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Academician
STEPAN IL'ICH MIRONOV
1883-1959

# ACADEMICIAN STEPAN IL'ICH MIRONOV[1]

Academician Stepan Il'ich Mironov, a noted scientist in the field of petroleum geology, passed away after a short illness, on March 30, 1959, in his 76th year.

He was born of a peasant family, in 1883, in the village of Poroshino, the former Vyatskaya Province. He revealed great ability, in early childhood; after graduating from the village school, he entered the Vyatka Real Gymnasium, and in 1902 he passed the very difficult competitive entrance examination in the Petersburg Mining Institute. The young Stepan Il'ich was twice expelled from the Institute for participating in revolutionary activities among the students, and succeeded in graduating only in 1914.

S.I. Mironov began his scientific activity while a student, when he carried out an independent hydrogeologic study of Cheleken Island. In 1909 and 1910, he participated in a study of the oil and coal areas of Sakhalin Island; in the following years, he carried on a geologic study along the right of way of the proposed Kama-Irtysh canal, and a hydrogeologic and geologic study of the former Yekaterinoslavskaya Province.

The performance of these tasks revealed his scientific bent, and in 1913 he was employed by the Geologic Committee.

During his first years with the Geologic Committee, Stepan Il'ich carried out geologic investigations in the Ural-Emba oil region, which have resulted in new and interesting data on the presence of oil in that area. The First World War interrupted his work; he was dispatched to the battle zone to carry on investigations in the Trapezond fortified area.

He resumed his scientific activity in 1917, when the Geologic Committee appointed him assistant geologist; he was promoted to geologist in 1921, and then senior geologist. From 1918 to 1920, he studied the geologic structure of the former Vyatskaya Province and actively participated as assistant to I.M. Gubkin in nationalizing the oil industry, and as a consultant to the Embaneft' Trust.

The years 1919 and 1920 witnessed the publication of S.I. Mironov's works on the Ural-Emba region. They contain excellent descriptions of the geology and individual fields of the area on the basis of his personal observations, with special attention given to its oil possibilities. Even at that time, he started to apply some of the new methods of study of oil fields, such as saturation and production maps for the Dossor field. His brilliant work in the Ural-Emba region, summarized in his Exploration Work in the Ural-Emba Region (Leningrad, 1928) has advanced S.I. Mironov to the ranks of outstanding petroleum geologists of the country.

An important stage in the scientific activity of Stepan Il'ich was his participation in the Sakhalin study, in 1925 and 1926. These investigations led to many new contributions to the knowledge of oil-bearing formations and the tectonics of the east coast of the island; they served as a basis for further study of its oil deposits.

Stepan Il'ich also did much work in the Volga-Ural oil and gas province where he headed, beginning in 1938, a large group of geologists, and carried on investigations in Tatariya, the Kuybyshev Volga Region, and other areas. These works resulted in voluminous publications and in practical recommendations to the oil industry.

In 1946, S.I. Mironov was elected Active Member of the Academy of Sciences, USSR. From then on, his work was connected with scientific institutions of the Academy.

From 1948 on, S.I. Mironov headed the Section of Petroleum Genesis at the Petroleum Institute, Academy of Sciences, U.S.S.R., and then the Laboratory of Petroleum Genesis, at the same Institute. As the director of this

[1] Akademik Stepan Il'ich Mironov.

laboratory, he published a number of theoretical works shedding light on this most difficult problem and charting a course for its practical solution. He developed and supported chiefly the research on natural bitumens and crude oil in connection with their geologic environment, making use of the latest methods, such as radiation chemistry, chromatography, infrared and ultraviolet spectroscopy, etc. A monograph Oil and Bitumens of Siberia, written in collaboration with his laboratory coworkers and dealing with oil prospects in Siberia, was published in 1958.

S.I. Mironov has contributed much to the development of the oil industry in the U.S.S.R., both as a scientific organizer and as a true pioneer in some fields of exploration and study of oil fields. He organized and directed many large geologic organizations. Thus, he initiated in 1929 the largest petroleum geologic institute of the U.S.S.R. — the All-Union Petroleum Scientific Research Geological Prospecting Institute (VNIGRI). He was first its director, then scientific adviser and did not cease his consulting activity till 1948.

In the period of activity of the VNIGRI, and at the initiative and continuous support of Stepan Il'ich, the application of geophysics was initiated and extensively developed for the search for oil. He also initiated the wide application of micropaleontology which is now being used in all research units of petroleum geology.

From 1947 to 1950, S.I. Mironov was Director of the Sakhalin Base and then Chairman of the Sakhalin Affiliate of the Academy of Sciences, U.S.S.R.

From 1949 on, Stepan Il'ich was continually reelected to the Bureau of the Section of Geological-Geographical Sciences, Academy of Sciences, U.S.S.R. With his innate scrupulousness and punctuality, he actively participated in its work, especially as the head of the award committee for best works in the field of geology. Ever well-disposed toward his fellow man, and a man of principle in his scientific views, he would not compromise and he maintained his objectivity in decisions passed by the commission under his direction.

From 1951 and to the end, Stepan Il'ich also was on the Editorial Board of this magazine. His broad erudition, integrity, and frankness in the analysis and evaluation of scientific works offered for publications acquired for him the love and deep regard of his coworkers on the Board and of the authors. In critical instances of editorial crisis, he successfully championed the strict scientific line for the Board and the magazine.

For his fruitful scientific work, S.I. Mironov was awarded the order of Red Labor Banner and medals of the Soviet Union.

The industrious life of S.I. Mironov, his leading role in many undertakings in petroleum geology, and his excellent personal qualities have earned him not only well-deserved scientific recognition but love and deep esteem, as well. A man of amazingly simple habits, responsive, and accessible to all — especially to a beginner — Stepan Il'ich was straightforward, both in science and in life.

A true patriot, ardently loving his country, he deeply believed in the coming triumph of Communism and he gave his all to the service of his country.

We shall always remember Stepan Il'ich as an outstanding scientist, a fine man, and our friend.

D.I. Shcherbakov, N.S. Shatskiy,
G.D. Afanas'yev, K.A. Vlasov,
O.D. Levitskiy, M.F. Mirchink,
K.R. Chepikov, F.V. Chukhrov,
G.P. Barsanov, A.D. Yershov,
V.S. Yablokov, S.D. Adashnikova

# THE METALLOGENY OF THE PACIFIC BELT[1]

by

M. M. Konstantinov

The determination of geochemical features of various orogenic provinces and of their relationship to the mechanism of their development plays an important part in establishing a modern metallogenic theory. In their geochemical characterization of orogenic zones, Soviet geologists pay much attention to the so-called Pacific mineralization belt. This interest is due first to the presence in the northeast U.S.S.R. of rich mineral regions; and, second, to certain features of this belt, revealing geochemical regularities in the distribution of a number of minerals in the earth's crust, in a manner more definite than in other metallogenic provinces.

The recognition of a Pacific ore belt began to be formed almost a century ago.

The first geologist to suggest the idea of such a belt was I.A. Paletika [3] who traced two major gold-bearing zones (he called them, "lines") along the American and the Asian Pacific coasts. Later, V.A. Obruchev [2] enunciated his concept of a great similarity in the geologic structure and metallogeny of the Asian and the American sides of the Pacific coast; on that premise, he gave a generally positive evaluation of the mineral possibilities in the Soviet Primor'ye (Maritime Region). Of great importance in the knowledge of metallogeny and the mineral wealth in the northeast U.S.S.R. was A.Ye. Fersman's work [5] outlining a "Mongol-Okhotsk Mineral Belt" which embraces a considerable part of the Asian sector of the Pacific Belt.

However, the most fundamental description of the metallogeny of the Pacific belt was given by S.S. Smirnov in his well-known work On the Pacific Mineral Belt [4].

The main thesis of S.S. Smirnov's work was that there are two metallogenic belts: the interior, essentially a copper zone; and the exterior, essentially a tin zone (Fig. 1). The presence of these zones was related to the Mesozoic and Cenozoic fold structures of the Pacific coastal provinces.

In the decade since the publication of S.S. Smirnov's work, no new regional study has appeared on the Pacific belt as a whole; however, the geology and mineralization of its individual parts have been investigated in more detail.

A few years ago, some new data suggested to a number of Soviet geologists studying the metallogeny of the Far East (O.D. Levitskiy, Ye.A. Radkevich, etc.) that it was considerably more complicated than had been previously supposed.

In 1956 a very interesting paper of V.K. Chaykovskiy was published [7], containing vast new material on many regions of the Pacific belt. That author attempted to explain the metallogenic zonation of these regions on the basis of his concept of an intrageosyncline.

In his opinion, any mineral province formed at the site of a geosyncline has a "leucocratic" mineralization, i.e., Pb + Zn (vein), Mo, W, Sn, in its axial part; and a "mesocratic" one, i.e., Cu, Au, Ag, Cr, Ni, Pb + Zn (pyritic), at its periphery. The first one was formed at an earlier stage accompanied by folding; the second one, at a later stage when faulting was developed.

There have been attempts at metallogenic generalizations for individual sectors of the belt in other countries; we cite specifically a short paper by the Philippine geologist G. Scholey [8], which contains some new data on mineralization of the Pacific copper zone.

These data suggest a continuation of the copper zone from Luzon Island, where it has been fixed by S.S. Smirnov, farther south, through the Philippines to Indonesia. A chiefly spatial relationship between the copper mineralization and diorites and andesites is noted, along with the diversity of its manifestation. Chalcopyrite is the most common copper

[1]K metallogenii tikhookeanoskogo poyasa.

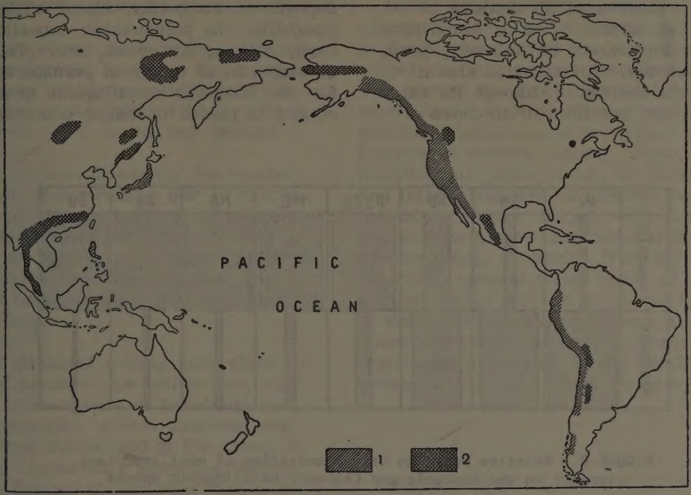


FIGURE 1. The Pacific Mineral belt (after S.S. Smirnov, [4])

1 -- interior zone; 2 -- exterior zone.

mineral, with argentite and native copper in some deposits; a Cu and Au association is widely developed, with the Cu and Mo association on the Island of Marinduque.

Along with new factual material on mineralization of the Pacific belt, there appeared voluminous monographs on its geology and structure. All this calls for certain refinement, supplements, and a further development of Smirnov's metallogenic scheme.

S.S. Smirnov considered the tectonics and metallogeny of the Mesozoic and Cenozoic Pacific fringe as a whole, without subdividing it into separate stages, as the most important basis for future investigations.

The last decade has witnessed much progress in this very direction, by delineating more precisely the individual tectonomagmatic stages of the Pacific fringe and their metallogenic features. At the present time, it becomes possible to recognize, in first approximation, two main metallogenic epochs for the entire Pacific coast: the Mesozoic and the Cenozoic. A more detailed differentiation is possible, but it will carry more reservations, because of inadequate synchronization and correlation of geologic data pertaining to the continents.

A reservation should be made because we include the Laramie phase (of A. Eardley) into the Cenozoic phase which was initiated at the end of the Cretaceous and continued into the Tertiary.

As noted by S.S. Smirnov, typical elements for the entire Mesozoic and Cenozoic folding are Cu, Ag, Au, Zn, Cd, Hg, Sn, Pb, As, Sb, Bi, S, and Te. These elements exhibit a sharp differentiation in time; as a result, some of them are more characteristic of Mesozoic metallogeny, some others of the Cenozoic. The relative distribution of total resources of some of the minerals in the Mesozoic and Cenozoic metallogenic epochs is presented in table, Figure 2.

This table shows that the Mesozoic metallogeny is marked by the predominance of W and Sn. The largest deposits of these metals, accounting for a major portion of their world reserves, are known from China, Malaya, Burma, and the northeast U.S.S.R.

Only the large areas of Bolivia and the Soviet Maritime Region are related to the Cenozoic metallogeny. The main reserves of Sb, too, appear to belong here, because the origin of the world's largest Sb deposits in China is associated, according to the recent data, with the Yan'shan' igneous activity. The origin of these deposits remains very obscure, and substantial changes are possible in its interpretation. Specifically, the association of the largest of them with metamorphic phenomena is not ruled out.

There are a number of Sb deposits in Mesozoic fold structures of other Asian provinces, but the importance of antimony, here, decreases markedly. Antimony is also a typical Cenozoic element. Although its reserves of that age are inferior to those of the Mesozoic, its deposits are counted in hundreds and are distributed throughout the American Pacific belt and in Japan. Many of them are mined; their total output is over 50 per cent of the world production of antimony.

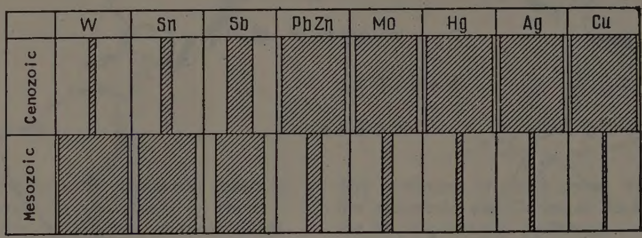


FIGURE 2. Relative position of concentration of most important elements in the Mesozoic and Cenozoic metallogenic epochs.

The Cenozoic metallogeny is characterized by a marked predominance of such elements as Cu, Ag, Hg, Pb, Zn, and Mo.

Mercury, geochemically cognate to antimony, exhibits a stronger predilection for Cenozoic metallogeny. Hundreds of mercury deposits are scattered over the American Pacific coastal region, with the largest of them known from the Coast Ranges of California (New Almaden, New Ydria). The prime importance of molybdenum in Cenozoic metallogeny is determined chiefly by the fact that most of the world supply of this metal comes from the Climax deposit whose formation is related to Cenozoic intrusive activity. Other contemporaneous molybdenum deposits, although fairly numerous, are as a rule, small. Molybdenum is fairly typical of the Mesozoic metallogeny, as well, inasmuch as such deposits are widely distributed, with many of them attaining a comparatively large size; on the whole, however, Mesozoic reserves of molybdenum are much inferior to those of the Cenozoic. Pb, Zn, and Ag also are typical of Cenozoic metallogeny.

Although the Yan'shan' phase has associated with it numerous polymetallic commercial deposits in China and Northeastern Asia, often also carrying silver, the concentration of these metals in Cenozoic structures is still outstanding. Here belong such well-known deposits as Park City, Coeur d'Alene, Tintic, Leadville, the polymetallic deposits of Mexico, Peru, Bolivia, Argentina, etc. The extensive development of silver is perhaps most typical for this Cenozoic metallogenic group where it occurs in places in unique concentrations, such as the Sunshine mine in the Coeur d'Alene area.

The distribution of copper mineralization through the Pacific belt has been described in detail by S.S. Smirnov. It should be added only that all copper of the "interior" zone of the belt is associated with Cenozoic metallogeny, while the Mesozoic metallogeny comprises a virtually insignificant number of presently little known deposits, mostly in China.

Besides the basic differences in the distribution of principal elements between the Mesozoic and Cenozoic metallogenies, the two seem to differ in the development of genetic types of ore deposits.

A startling feature of Cenozoic metallogeny is the abundance of peculiarly complex paragenesis, rarely occurring in other provinces, such as low-temperature gold-silver ores, copper-tin-uranium ores, ores of the Kuramono type, etc. Generally speaking, the development of near-surface telescoped deposits is a characteristic feature of the Cenozoic. A "hurricane" distribution of some metal concentrations has also been noted, wherein the main body of metal deposits is concentrated in a few isolated spots, with numerous other deposits accounting only for a small fraction of it. Thus, the Climax mine carries about 98 per cent of all Cenozoic molybdenum reserves; the Unchia Lallagua, Calniry, and Wanui mines account for about 50 per cent of the tin in the American sector of this belt.

Such are, in general outline, the differences

in the Mesozoic and Cenozoic metallogenies.

The most important seem to be, however, not these metallogenic features, but the quite definite ideas on an historical regularity in the development of the folded Pacific fringe; this has become clear in the last decade.

According to these concepts, the entire western sector of the Pacific belt is characterized by a progressive growth of younger folded structures along the fring of older ones — in other words, a gradual migration of orogenic zones from the Siberian, the Chinese, and the Australian platforms toward the oceanic trough.

Periods of intensive folding gave place to movements of another type which lead, specifically, to submergence of individual land areas. For example, a vast continent east of Australia was submerged at the close of the Cenozoic. Apparently somewhat earlier, the so-called Bering-Youkon sank where the Bering and Okhotsk seas are now [7]; some students believe that a considerable portion of southern China is now undergoing subsidence.

These downward movements of individual areas along the western Pacific coast coincide in time with the development of uplifts along the American sector. On the whole, however, they are of subordinate significance and do not alter the main line of development of these segments of the earth's crust, which is expressed — as previously noted — in a progressive growth of fold structures along the platform edges, and in their gradual migration toward the Pacific trough. In the American sector, in contrast, there was a gradual advance of orogenic processes toward the continent. The main factor in this sector was the rebuilding of the marginal part of a platform province, by tectonic phases following each other, into a geosynclinal or parageosynclinal zone and then into a fold structure.

For the North American continent, this topic is well treated in A. Eardley's monograph [1]. With his data, we have compiled a schematization which illustrates this process fairly well (Fig. 3). A peculiar development of fold provinces of this type has been considered by Yu.M. Sheynmann [6].

On the whole, the entire course of tectonic development in provinces adjacent to the Pacific is marked by a progressive eastward movement of zones of folding. This phenomenon was noted briefly by S.S. Smirnov; a more complete understanding, however, did not come about till recent years. Such a regularity of tectonic development predetermines the spatial distribution of geochemical zones in the Pacific belt.

In its Asian sector, ore zones of earlier Mesozoic stages are naturally located nearer to the platform, with the later Cenozoic stages located nearer to the oceanic trough. The picture for the American sector, on the other hand, is quite different and very peculiar, inasmuch as it exhibits a reverse position of mineral zones. First, each new metallogenic phase, here, is shifted eastward and inland, relative to mineral zones of the preceding stages; second, they are superimposed on these older mineral zones and rework them, in depth. With the process so oriented, mineralization zones of relatively earlier stages may be buried at the bottom of the eastward moving oceanic trough. This course of events is well illustrated in a metallogenic diagram of the Cordillera province, U.S.A., which we have compiled

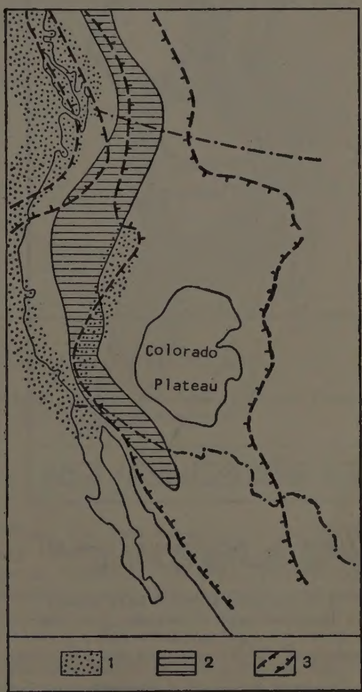


FIGURE 3. Plan of development of orogenic processes in the Cordillera province, U.S.A.

1 -- regions of predominant development of pre-Nevadan orogeny; 2 -- principal areas of the Nevadan orogeny; 3 -- regions of predominant development of post-Nevadan orogeny.

from published sources (Fig. 4). Here, a tungsten belt, marked by a predominance of scheelite deposits in contact zones of granite intrusions, is a peculiar relict of Mesozoic (Nevadan) metallogeny, with actively superimposed processes associated with a later intrusive activity of the Laramie and upper Tertiary. This last intrusive stage has produced a series of ore deposits east of the tungsten belt, the most abundant — both in number and reserves — in Cu, Pb, Zn, and Mo. The copper and polymetallic belts, discernible here, are closely related to the numerous — and generally small intrusions of acid magma, chiefly Tertiary in age. The tungsten ore showings and deposits in the copper and polymetallic belts are also related to these younger intrusions. They differ sharply from deposits of the tungsten belt proper, appearing as they do in peculiar low temperature veins (Boulder County) where the mineralization is represented by ferberite with cinnabar and antimonite.

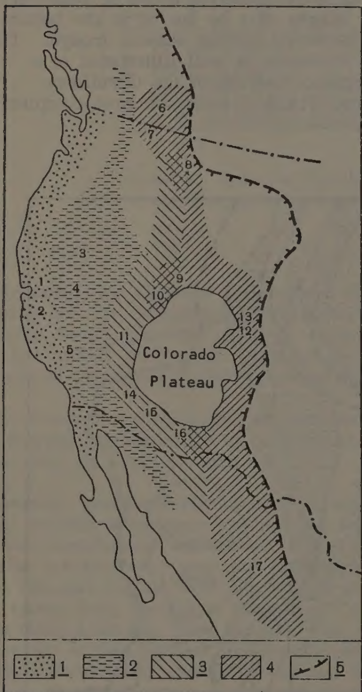


FIGURE 4. Metallogenic scheme of North-American Cordilleras.

1 -- Mercury belt of California; 2 -- tungsten belt of Nevada; 3 -- copper belt; 4 -- polymetallic belt; 5 -- boundary of folded province and platform.

Numbers on map refer to deposits: 1 -- New Almaden (Hg); 2 -- New Ydria (Hg); 3 -- Mill City (W); 4 -- Outhorn etc. (W); 5 -- Bishop (W); 6 -- Sullivan; 7 -- Coeur d'Alene (Pb,Ag); 8 -- Butte (Cu, Pb); 9 -- Tintic (Pb); 10 -- Bingham (Cu, Pb); 11 -- Payoch (Cu); 12 -- Leadville (Pb); 13 -- Climax (Mo); 14 -- United Verdi (Cu); 15 -- Miami (Cu); 16 -- Morancy Clay; 17 -- polymetallic deposits of Mexico (Santa Eulalia, Santa Rita, Pachuca, etc.).

The superposition of younger mineralizing processes on ore areas of the pre-Nevadan and Nevadan tectonomagmatic stages, to the west, is graphically emphasized by the formation of the mercury belt of the California Coast Ranges, west of the tungsten belt. The formation of mercury deposits, apparently initiated in the Tertiary, is still continuing.

Such an orientation of metallogenic processes, in itself, precludes the possibility of formation of "exterior" and "interior" metallogenic zones, in the meaning of S.S. Smirnov's terms, i.e., zones disposed concentrically along the periphery of the Pacific basin. As an approximation, the position of structural and metallogenic zones of the Pacific may be presented from recent data, as shown in Figures 5 and 6.

In the light of these considerations, some of the contradictions in S.S. Smirnov's metallogenic scheme are revealed and explained.

First of all, his scheme places an exaggerated emphasis on the tin mineralization in the American sector. It has become quite evident, in the last fifteen years, that tin is virtually lacking along the entire North American stretch of the belt. It became clear from later investigations that the small showings of tin in Alaska, Nevada, Wyoming, and Mexico, regarded as a sort of "tin background" for larger commercial deposits, have not lived up to the expectations. It becomes evident, now, that one of the most typical metallogenic features of the North American continent is this almost complete lack of tin. Those known insignificant deposits and mineralogic occurrences are of no importance in such broad metallogenic generalizations as the scheme of metallogeny for the Pacific belt.

In the South American part of this belt, major tin deposits of world significance occur only in Bolivia; elsewhere along its length, tin deposits of any significance are lacking. On this tin-free background of the American half of the Pacific belt, the Bolivian tin and tungsten zone stands out not as typical but rather as a unique phenomenon. The reason


FIGURE 5. A scheme of basic tectonic elements for the Pacific belt.

1 -- Province of Alpine folding; 2 -- province of Mesozoic folding; 3 -- province of Alpine folding superimposed on that of the Mesozoic; 4 -- outline of Sima Province.

zone should be looked for not in the regularities common to all of the Pacific belt but rather in the special geologic position of this region. S.S. Smirnov noted that this region is located at the junction of the Andean fold province where a large trough crosses the Brazilian shield, at the place where the Andean trend veers sharply and where Siluro-Devonian flysch is developed, i.e., under conditions not duplicated elsewhere in the belt.

The presence of the Bolivian tin and tungsten province confirms, therefore, S.S. Smirnov's concept that local conditions are more important in metallogeny of individual regions than the regularities common to the entire Pacific belt.

Thus, the data extant on tin in North and South America give no basis for distinguishing here an "exterior" tin zone, in any respect equivalent to the East Asian tin and tungsten belt.

The possibility of tying the tin and tungsten deposits of Asia and America into a discrete metallogenic belt is ruled out also because of their age difference. All tin deposits and ore showings of the American sector (including Bolivia) are now unequivocally believed to be Tertiary, while tin deposits of the East Asian belt are chiefly Upper Jurassic or Lower Cretaceous in age.

The combination of data cited on the

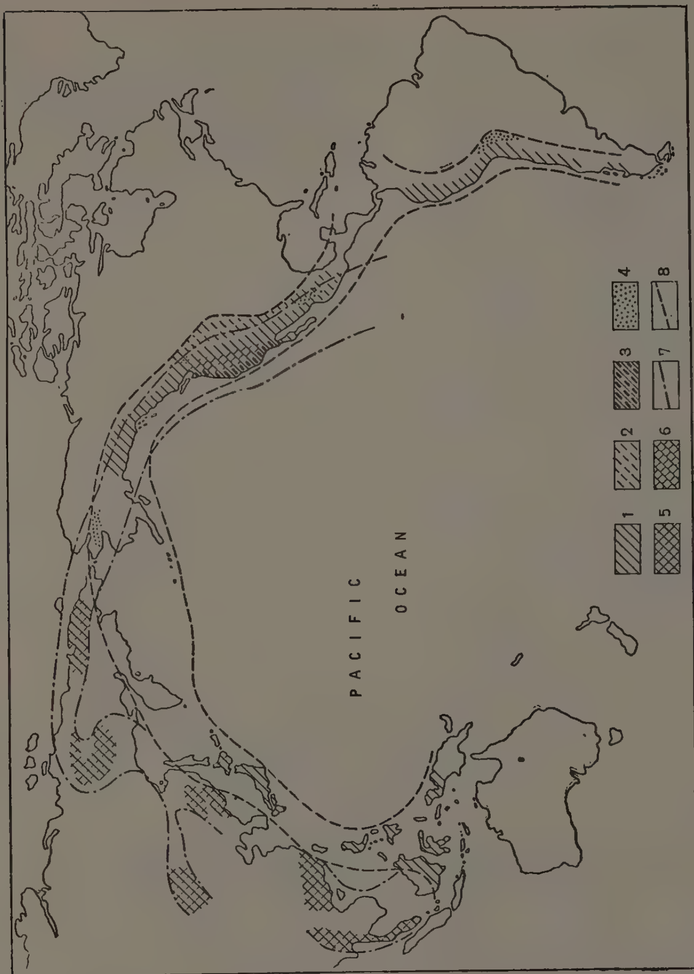


FIGURE 6. Scheme of principal metallogenic elements of the Pacific belt.
1 -- Regions of chiefly copper mineralization, of Tertiary age; 2 -- regions of Tertiary polymetallic mineralization; 3 -- regions of Tertiary mercury mineralization; 4 -- regions of Tertiary tin mineralization; 5 -- regions of Mesozoic tin and tungsten mineralization; 6 -- regions of Tertiary tungsten mineralization; 7 -- outline of East Asian Mesozoic ore belt; 8 -- outline of the Pacific Tertiary ore belt.

regularity of formation of the Pacific coastal fold zones and their tin content suggests the absence of an equivalent of the East Asian tin belt on the American side.

Turning now to the diagram of disposition of metallogenic zones, shown in Figure 6, it must be stated that the presence of a copper zone, as conceived by S.S. Smirnov is not to be doubted. It stretches along the entire Pacific coast of South and North America, and farther on along the chain of island arcs of Asia, according to the data of the same author, and somewhat amplified by G. Scholey.

On the American continent, two subzones are locally discernible within this zone: one, essentially copper, is located near the coast; and the other, polymetallic, is somewhat farther inland. Where the fold province widens, the mineralization zones are "laid out" more distinctly, so that certain secondar ore belts can be differentiated in addition to the main ones (see Fig. 4). Conversely, where the fold province is narrowed and compressed, the mineralization zones are piled up, as if telescoped.

The similarity of composition in ore deposits, and the relation of most of them with

either the Tertiary or Upper Cretaceous, leave no doubt as to structural and genetic unity of this entire copper belt.

The situation is quite different in the tin and tungsten zone.

The East Asian belt, stretching through China, the northeast U.S.S.R., and approaching Alaska from the north, veers to the southeast and is overlain here by a younger fold belt which has shifted to the east with relation to the tin and tungsten belt, because of the migration in that direction, of the fold zones and metallogeny.

On that part of the North American coast where the Laramie and the Alpine tectonics and metallogeny were superimposed on provinces of the Nevadan orogeny, the possibility should not be ruled out, of some relicts of the Nevadan metallogeny (Nevada tungsten belt) being preserved along with evidence of tin and tungsten mineralization, as so-called regenerated formations. The evidence of tin mineralization in Alaska, Nevada, and perhaps Mexico, which attracted S.S. Smirnov's attention, may turn out to be of this kind.

In conclusion, there is a question arising naturally from what has been said — what of the Pacific mineralization belt?

The expanded interpretation of this term, used hitherto to include nearly the entire province from the North American and the Brazilian platforms to the Siberian platform, was based on the concept of a simple concentric arrangement of fold and metallogenic zones about the Pacific. The now apparent more complex and heterogeneous structure of the Pacific belt casts doubt on the validity of such an interpretation.

We deem it more correct to interpret this term to mean a mineralization belt related to the province of Cenozoic folding. As to the development of Mesozoic folding in Asia, the vast ore belt related to it and not duplicated on the American continent, should be taken out of the Pacific mineralization belt and named (in S.S. Smirnov's nomenclature) the East Asian mineralization belt.

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# SOME PROBLEMS ON THE ORIGIN OF URANIUM MINERALIZATION, IN CONNECTION WITH THE STUDY OF EFFECTIVE POROSITY OF ORE-BEARING CARBONATE ROCKS[1]

by

V.I. Danchev and V.V. Ol'kha

Extensive data on sedimentary uranium ore deposits has been gathered in the last decade. Such ore deposits have been discovered in sedimentary rocks of most diversified ages, from the most ancient, usually associated with ore deposits of a metasedimentary origin [3, 4, 5, 7, etc.], to modern peat beds [14, 15] where uranium is being accumulated in sediments formed under our very eyes.

Because of the high migrative capacity of uranium and of its tendency to form numerous chemical compounds, the occurrences of its ore concentrations in sedimentary rocks are so diversified even within the same deposit that their study often leads to quite different, at times contradictory, conclusions. Uranium deposits associated with carbonate sedimentary sequences, some aspects of whose origin are treated in this paper, are not an exception in this respect. Their origin has perhaps the greatest number of different explanations, evidently because of the more or less extensive redistribution of ore material at different stages of formation of ore-bearing rocks.

The prevailing concept of the conditions of formation for these ore deposits is that of a normal genesis of the ore substance with its more or less intensive diagenetic and epigenetic redistribution. The adherents of this view believe that the primary concentrations of uranium compounds originated during the sedimentary stage and increased in the diagenetic stage. The accumulation of uranium in sediments was assisted by a paleogeographic environment which promoted !eaching of its compounds in the destruction of source rocks on the continent, and which determined their fixation in littoral reaches of basins where reducing conditions prevailed because of the concentration of organic matter. These conditions promoted precipitation of uranium compounds from the ooze water, and their sorption by organic matter and the colloid fraction of the sediment [6, 10, 14]. This view of the origin of uranium ore deposits in carbonate rocks is shared by the authors of this paper.

There is, however, another view on the origin of these deposits, which regards them as hydrothermal, or more exactly, hydrothermal-metasomatic. In this view, mineralizing solutions moved along tectonically disturbed blocks, penetrating the most porous layers of carbonate rocks; where there was an excess of organic matter, uranium compounds were deposited, in addition to their fine precipitation in oolites, in shells of macro- and microfauna, and in the carbonate cement of rocks. In the course of time, and after a comprehensive study of such deposits, the argument for a hydrothermal and hydrothermal-metasômatic origin of uranium mineralization in them has lost most of its factual substantiation. There were other theories according to which the mineralization came about not as a result of the altering action of thermal solutions but rather through deposition of uranium brought in from outside, by formation waters in their migration through the most permeable rock layers. In either case, one of the main arguments for the addition of uranium from outside is the higher effective porosity of ore-bearing rocks as compared with the uranium-free rocks, i.e., less permeable to the mineralizing solutions.

For this reason, in our study of uranium ore deposits associated with carbonate sediments (limestone and in part with dolomite), we deemed it expedient to study certain physical and mechanical properties of ore-bearing rocks in addition to using the standard petrographic and geochemical methods. First of all, a mass determination was made of their effective porosity. The results of this study are the basis of this paper.

In our determination of effective porosity of ore-bearing carbonate rocks, we applied a somewhat modified method of I.A. Preobrazhenskiy [8] which he had worked out for dense rocks and which is based on the

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[1]Nekotoryye voprosy genezisa uranovogo orudeneniya v svyazi s izucheniyem effektivnoy poristosti rudosoderzhashchikh karbonatnykh porod.

absorption of water or some other fluid by specimens previously dried out and reduced to the same weight. The saturation of specimens with water was done under a vacuum, in a specially equipped exsiccator. The difference in weights of a saturated and a dry sample gives an idea of the volume of the pore space connected by water. The ratio of this volume of pore space to the volume of the rock is the well-known porosity coefficient (Pef).

The most common petrographic varieties of principal ore-bearing rocks were selected from mines and exploratory drill holes, in the determination of effective porosity. Present among them were varieties with oolitic, organic, and crystalline structures, determined by the predominance of oolites, organic remains, or the lack of both, and by the structure of the carbonate matrix.

The most common ore-bearing rocks are oolitic and organic limestones. The first are made up of spherical or ovoid oolites (Fig. 1-1) with a clearly expressed concentric and a more or less distinct radial structure. Their size ranges from 0.3 to 1.2 millimeters. Occurring in their nuclei are shell fragments, in places well-preserved whole foraminifera, minute crystals of calcite or less commonly of quartz, and other clastic minerals. The clastic fraction in oolitic limestone seldom exceeds 8 per cent. The determination of effective porosity in oolitic specimens has shown that they have a minimum porosity compared with other petrographic varieties. The average value of Pef, from 252 determinations, is 4.3 per cent, with extreme values from 1 to 13 per cent. If the results of these determinations of effective porosity from 252 specimens are grouped by the frequency of the values of Pef, the bulk of the specimens — 189, or 75 per cent of the total — are distributed in the porosity range between 1 and 5.3 per cent; the average value of Pef for this restricted group will be 3 per cent. The difference in the average value of Pef evidently is explained by the presence of limestones with an organic-oolitic structure, along with purely oolitic varieties: the effect of organic remains, however slight, appears to be sufficient to increase the effective porosity of this rock group.

Limestones with an organic structure (Figs. 1, 2) consist chiefly of fragments and well-preserved small shells of gastropods, pelecypods, foraminifera, remains of echinoderms, bryozoa, blue-green algae (siphonales), and other forms, all cemented with calcite. Some of the shell hollows are filled with more coarsely-crystalline calcite or with a pelitomorphous argillaceous carbonate. Some of the organic remains carry incrustations of small pyrite crystals giving the effect of a peculiar sulfide jacket over the shell. The average effective porosity, as computed from 172 determinations for this petrographic variety, is 5.2 per cent, with extreme values of 1.2 to 12.2 per cent. The bulk of specimens (75 per cent of the total) lie in the 2.6 to 9.3 per cent porosity range, with the average value of Pef 4.4 per cent.

Dolomite is the predominant ore-bearing carbonate rock with a crystalline structure; limestone is definitely subordinate. Thin-bedded pelitomorphous, cryptocrystalline (Figs. 1-3), and mesocrystalline varieties of dolomite with a typical zonal structure of their component rhombohedric crystals (Figs. 1-4) were present. There were also calcareous dolomites or dolomitic limestones. The results of their microscopic study show a wide development of the processes of secondary recrystallization, which commonly alters the original aspect of a rock almost completely, or to such an extent that its identity can only be guessed at by isolated features and outlines of a relict structure. Inasmuch as this group includes very diversified rocks genetically — from sedimentary pelitomorphous, thin-bedded dolomites to strongly altered recrystallized dolomitic limestones and calcareous dolomites — their effective porosity ranges most widely, from 0.5 to 22.5 per cent. The average of 82 determinations were 10.2 per cent. Undoubtedly, these rocks deserve a more detailed description; however, this is beyond the scope of this paper and is a subject of special study.

A comparison of effective porosity for the above-named petrographic varieties of carbonate rocks is given in Figure 2. Its outstanding feature is that the average effective porosity for these groups of rocks increases from the oolitic to the organic, and then to the crystalline varieties. Because of the presence of intermediate varieties between these groups (organic-oolitic, oolitic-organic, etc.), the porosity range of each of these varieties is wide; however, the most typical representatives of each group are marked by considerably narrower ranges, with the average Pef somewhat lower than for all of the specimens in each variety.

The results of these investigations show that rocks from principal ore-bearing layers which include the oolitic and organic limestones, are marked by an effective porosity considerably lower than that of dolomites and calcareous dolomites; the latter are of secondary importance as ore-bearing rocks, although they have a much higher effective porosity.

In order to determine quantitative relationships between the value of effective porosity

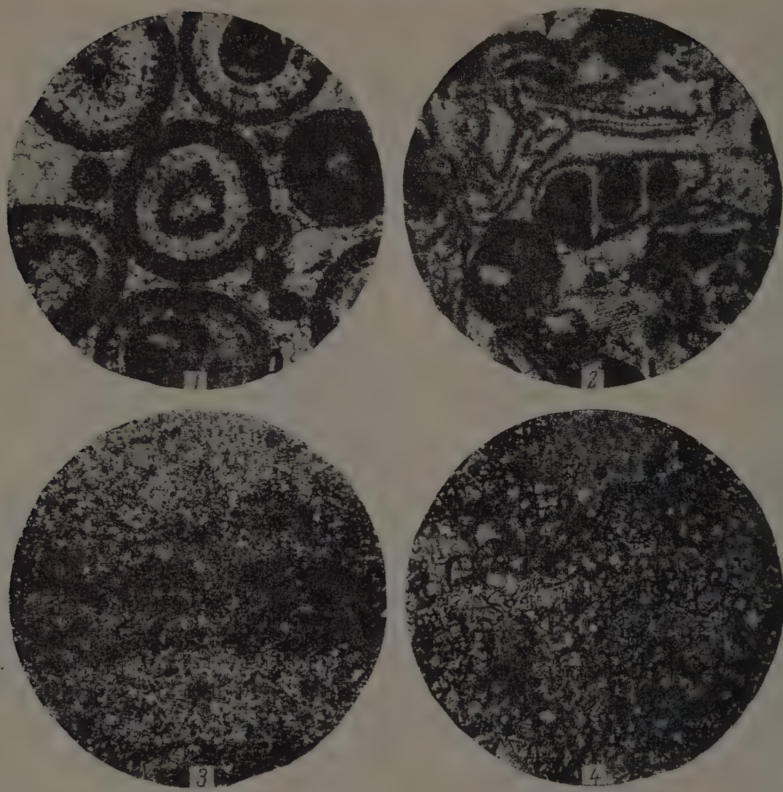


FIGURE 1. Petrographic varieties of ore-bearing rocks from uranium deposits associated with carbonate sedimentary sequences.

1 -- Oolitic limestone (30x); 2 -- organic limestone (16x); 3-4 -- crystalline dolomite and calcareous dolomite (30x).

and the uranium content in rocks, rock material was collected from "blind" (not exposed) lenticular ore bodies associated with oolitic limestones at depths of 500 to 550 meters. The selection of these particular examples was determined by our desire to avoid the effect of surface weathering and of active alteration of ore-bearing rocks. The control sections of various parts of an ore body with different uranium content contained chiefly ore-bearing oolitic limestone and underlying organic limestone and dolomite and calcareous dolomite below the latter. The determinations of effective porosity of the uranium content in rocks are plotted in a graph (Fig. 3).

Out of 159 specimens used in constructing Figure 3, 134 were oolitic limestones (Fig. 3-1); 12 organic limestones (Fig. 3-2); and 13 crystalline varieties (dolomites or calcareous dolomites). By their uranium content, all these specimens may be divided into three groups: lean, medium, and rich in uranium. The peculiar distribution of points in Figure 3 is of interest. Its lower part (I) represents specimens from all three varieties of ore-bearing rocks; their effective porosity ranges from 1 to 15 per cent, with crystalline specimens displaying the highest porosity, as expected. They are concentrated chiefly in the lower right of the graph. The organic ore-bearing limestones occupy a position intermediate between the crystalline and oolitic varieties.

The middle part of the graph, with its concentration of medium-rich uranium ores (Fig. 3-II), is marked by an obvious

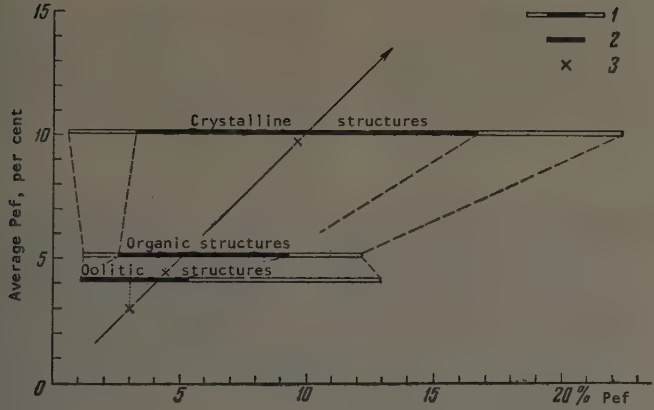


FIGURE 2. Graph of effective porosity of principal petrographic varieties of carbonate rocks (oolitic, organogenous, and crystalline).

1 -- Range and extreme values of Pef for each petrographic variety of carbonate rock; the level of the line corresponds to the average value of Pef for each variety; 2 -- range and extreme values of Pef for 75 per cent of all specimens analysed of each petrographic variety; 3 -- average effective porosity for 75 per cent of specimens from each petrographic variety; arrows show the change in effective porosity (Pef), from one variety to another.

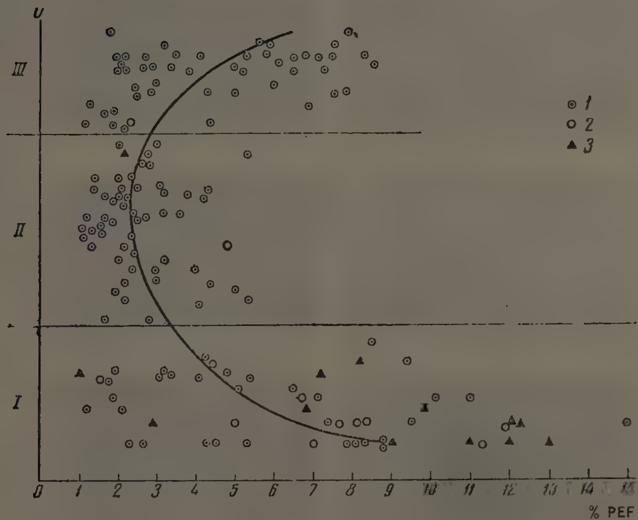


FIGURE 3. Relationship between uranium content and effective porosity of ore-bearing carbonate rocks.

1 -- Oolitic limestone; 2 -- organic limestone; 3 -- crystalline dolomite and calcareous dolomite; I -- lean ores; II - ores with an average uranium content; III -- rich ores.

predominance of oolitic limestones which make up ore bodies in this segment of the deposit. A single specimen comes from organic limestone, and another from crystalline dolomite. These specimens are more uniform in their effective porosity, being characterized by Pef of 1 to 5.5 per cent, mostly of 1 to 3 per cent. Specimens of rich ores (Fig. 3-III) come from oolitic ore-bearing limestones; their effective porosity, however, has a considerably wider range (from 1 to 9 per cent).

The change in the average value of effective porosity for each group, with the gradual rise in their uranium content, is represented by the curve in Figure 3. Its lower segment reflects the inverse relationship between the uranium content in rocks and their effective porosity; then there is a break in the curve, after which the effective porosity in rich ore specimens, in the upper part of the graph, rises somewhat with their uranium content.

This peculiar distribution of points on the effective porosity-uranium content graph of ore-bearing rocks is explained, in our opinion, by certain genetic features of sedimentary uranium deposits associated with carbonate rocks.

Specimens in the lower part of Figure 3, marked by the greatest variety in both microstructure and effective porosity, belong to rocks either immediately above or immediately below the ore-bearing layers, or else represent the peripheral parts of lenticular ore bodies or of their stratigraphic equivalents. The distribution of comparatively lean ores in them is very uniform. This is illustrated by X-ray photographs of a lump of rich ore (Fig. 4-1).

The bulk of specimens, concentrated in the middle of the graph (Fig. 3), belong to the main part of ore bodies. They are marked not only by a higher uranium content but also by a fairly even distribution of ore concentrations, as illustrated in an X-ray photograph (Fig. 4-2).

The more or less even distribution of uranium minerals in ore-bearing oolitic limestones is evidently determined by their microstructural features, as witness an X-ray photomicrograph (Fig. 5) which suggests that the pelitomorphic substance of uranium niello ("black") participates in the building up of oolites and is related to a smaller extent to the calcite cement in rock. It should be noted that uranium mineralization in these

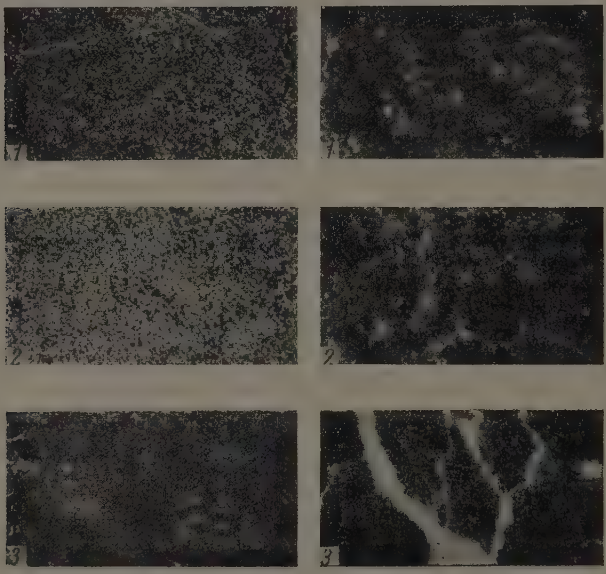


FIGURE 4. Distribution of ore concentrations in oolitic limestone.

1 -- Lean ores; 2 -- ores with a medium uranium content; 3 -- rich ores. Natural size.

rocks is closely related to the distribution of finely dispersed organic matter. The same rocks usually are enriched in iron sulfides (pyrite, marcasite, mel'nikovite) which, besides their occurrence in concretions of various sizes and form, impregnate the rocks as a whole, thus determining to a considerable extent their dark gray color.

Microscopic study of this type of ore-bearing rocks uncovers evidence of their participation in the earliest stages of rock making, and also fails to uncover well-defined evidence of secondary alteration. Limestone oolites whose nuclei and concentric layers are enriched in finely-dispersed uranium niello and pitchblende in association with argillaceous and organic substance could have been formed in the upper layer of a sediment only when the oxidation-reduction boundary line in that locality of an ancient basin passed above the sediment. According to V.V. Veber, I.I. Romm, V.G. Savich and other authors [1, 2], such a position of the oxidation-reduction boundary is very probable under the conditions of carbonate formation, because the oxidation potential of oozes is usually lowered with an increase in their carbonate content, with a parallel increase in the ratio of ferrous to ferric iron, and frequently with an increase in organic carbon. If we also consider with N.M. Strakhov [12] the probability of formation of oolites not only in the process of sedimentation but during the diagenetic stage of carbonate oozes, as well, the diagenetic transformation of sediments into rocks of this ore-bearing complex becomes "...not only a mineral-forming but also an ore-forming process..." [13]. A microscopic study of ore-bearing rocks reveals that ore-bearing oolites may fill up the pelecypod and gastropod chambers, fully duplicating their interior outlines, thus emphasizing the possibility of their formation during a diagenetic stage.

FIGURE 5. Ore-bearing oolitic limestone.

Uranium niello ("Black") is usually associated with oolites and permeates the calcite cement in rock more or less evenly. Diagenetic forms of ore concentrations. Magnification, 30X.

Besides the oolites, uranium compounds are concentrated in organic remains, in bones of large vertebrates (whose occasional findings are known from ore-bearing carbonate beds), and in thin suture-stylolitic seams which penetrate the limestone in different directions, chiefly along bedding planes. The formation of such concentrations appears to belong to a diagenetic stage.

However, many diagenetic forms of concentration of ore substance are subject to further development in later stages of formation of ore-bearing rocks. By that we mean primarily a further accumulation of uranium compounds in stylolitic structures. Having originated, as a rule, in early stages of rock formation, these suture-stylolitic structures appear to undergo their most intensive development during an epigenetic stage, changing at times to wider fractures filled with rock substance and determining the vein-like character of ores. Such richer concentrations of uranium minerals are illustrated in an X-ray photo of a specimen (Fig. 4-3).

The vein structure of ores is commonly associated with collomorphous pitchblende formations (Fig. 6) whose later origin is indicated by their growth over crystals of secondary calcite (Fig. 6-2). These epigenetic transformations of ore-bearing rocks took

place because of their somewhat higher effective porosity; for this reason, such specimens are grouped in the upper part of graph, Figure 3.

The increase in effective porosity and in the uranium content for some ore-bearing rocks is evidently related to their epigenetic transformation which occurred during uplifts when the sedimentary beds were brought into zones of lower pressures. L.B. Rukhin [11] gave the name of "regressive epigenesis" to those processes leading finally to surface weathering of sedimentary rocks as against the "progressive epigenesis", brought about

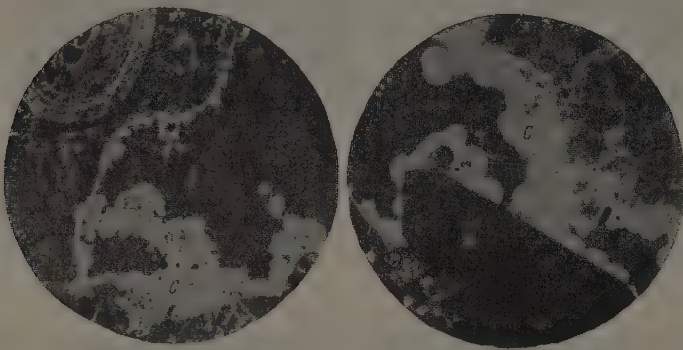

FIGURE 6. Ore-bearing oolitic limestone with cavities filled with collomorphous formations of pitchblende (c) and secondary calcite (k). Epigenetic forms of ore concentrations. Polished sections: 1 -- magnification 69X; 2 -- 168X.

by subsidence accompanied by a temperature rise, thus finally bringing the sedimentary rocks into a zone of metamorphism. Secondary alterations in sedimentary rocks, connected with the latter process, are discussed by L.V. Pustovalov and other authors [9].

The ore-bearing carbonate rocks we studied were exposed for a period as a result of orogeny and of subsequent erosion. Their component "blind" ore bodies, although never reaching the surface weathering zone or even the zone of active formation water exchange, nevertheless carry evidence of the developing processes of regressive epigenesis. This appears to explain the slight increase in effective porosity brought about by the intensified migration of formation waters carrying as yet a very low oxidation potential which facilitated the change of uranium niello to pitchblende.

When ore bodies are exposed at the surface, they become an arena for active oxidation processes leading to the formation of new mineral species — various phosphates, sulfates, and carbonates of uranium, which are typical of the oxidation zone of uranium deposits. In this process, the manner of distribution of ore concentrations throughout the enclosing rocks is a clear indication of their later and secondary origin.

The intensity of epigenetic processes is known to be determined by the position of ore bodies in a geologic structure, by the degree of dislocation of ore-bearing beds, fracturing, hydrogeologic features, and so forth; however, other conditions being equal, the differences in effective porosity of ore-bearing rocks are of substantial significance. Thus, for the above-named petrographic varieties of carbonate rocks, the epigenetic processes affect first of all, and most completely, the crystalline varieties, and less so the less permeable oolitic rocks. For this reason, the most diversified ore concentrations, and the greatest variety of mineral forms, occur in strongly recrystallized carbonate rocks.

Inasmuch as rocks accessible to study are those near-surface parts of uranium deposits strongly affected by secondary processes, geologists are naturally confronted with strongly altered enclosing rocks where the ore concentration is marked by its spottiness and diversity. All this greatly hampers the study of earlier stages of ore genesis, prior to an intensive epigenesis.

The experience in the study of uranium

deposits associated with different ore-bearing rocks shows that the frequent misunderstandings in determining their origin arise from the fact that the most recent transformation processes in ore deposits are thought to be the entire process. This also appears to be completely true for uranium deposits associated with sedimentary carbonate rocks.

## CONCLUSIONS

1. Effective porosity of sedimentary carbonate rocks is closely related to structural features. Of the petrographic varieties studied, oolitic limestones have the lowest effective porosity (4.3 per cent); it is somewhat higher in organic limestones (5.2 per cent), and it is about twice as high in carbonate rocks (dolomite and calcareous dolomite) with a crystalline structure (10.2 per cent).

2. The most widely developed ore-bearing carbonate rocks of our type of sedimentary uranium deposits are marked by the lowest effective porosity.

3. A study of the distribution of ore substance in various segments of ore bodies has shown that mineral dissemination predominates where the rock is least affected by the processes of recrystallization, leaching, and so forth. Samples of such rocks are marked by minimum effective porosity. This is in full agreement with the concept of a primary sedimentary origin of the mineralization, as set forth in the beginning of this paper.

Those instances where higher porosity has been determined are marked chiefly by vein mineralization, mostly a result of epigenetic migration of the ore components. The considerable increase in effective porosity of rocks is most commonly related to their secondary recrystallization and leaching. At the same time, the possibility should not be excluded that isolated segments of ore-bearing rocks had a high effective porosity to start with, which promoted a broader scope of epigenetic processes. In either case, the relationship between effective porosity of the enclosing rocks and the nature of distribution of ores in them is not to be doubted.

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# THE KHYUTA GABBRO-DIABASE INTRUSION IN THE IMANGDA RIVER VALLEY (NORTHWESTERN PART OF THE SIBERIAN PLATFORM)[1]

by

L. K. Afanas'yeva

The interest in Siberian traprocks has been growing with the progress of their study because they bear a number of useful minerals. Differentiated gabbro-diabase intrusions, commonly associated with deposits of certain valuable ores, are particularly interesting. Study has revealed that such intrusions, while differing from each other in composition and the nature and degree of differentiation and autometamorphism, differ also in mineralization. Because of our inadequate knowledge of Siberian traprocks, no regular relationship between these phenomena has been determined, as yet, although it would be of much interest, both scientifically and practically.

This paper describes briefly the results of petrographic study of a gabbro-diabase intrusion which, although poorly differentiated, is strongly autometamorphosed and is accompanied by lean copper-nickel sulfide mineralization.

This sheet intrusion, known as the Khyukta, is located in the northwestern part of the Siberian platform, in the Imangda Valley (right tributary of the Rybnaya River); it is conformable with Upper Silurian limestones, dipping east, at 10° to 14°, and it is traceable from south to north (by geophysical data), for over 10 kilometers. Because of poor exposures, its boundaries have not been established.

This intrusion has been penetrated through its full thickness by a borehole, which makes it possible to log its section, as follows, reading downward:

1) medium-grained gabbro-diabase, 1.70 meters;
2) coarsely crystalline prismatically-grained gabbro, 0.3 meter;
3) medium-grained gabbro-diabase, 12.85 meters;
4) fine-grained gabbro, 3.5 meters;
5) unevenly-grained taxitic gabbro-diabase, 6.85 meters;
6) fine-grained gabbro, 1.0 meter;
7) medium-grained gabbro-diabase, 33.3 meters;
8) fine-grained gabbro, 3.0 meters;
9) pegmatoid gabbro-diabase, 8.2 meters;
10) medium-grained gabbro-diabase, 24.8 meters;
11) fine-grained gabbro-diabase, 3.2 meters.

Gabbro-diabase predominates in the section, with gabbro intervals at various depths. The gabbro, as a rule, is accompanied by unevenly-grained taxitic or pegmatitic varieties, developed directly at the gabbro contact. The enclosing limestone, near the contact, is metamorphosed to hornfels with pyroxene skarn. The thickness of such altered rocks, in contact with both the top and the base of the intrusions, is about the same, not exceeding 20 meters.

The principal mineral components of gabbro-diabase are basic plagioclase, pyroxene, and olivine.

Plagioclase accounts for 53% to 66% of rock volume and forms mostly regular tabular crystals, twinned chiefly according to the albite and albite-carlsbad rules. The bulk of plagioclase crystals is represented by labradorite accompanied everywhere in the intrusion by more acid plagioclase, such as andesite No. 35, as well as by more basic varieties, e.g., bitovnite No. 80. The regular change in the plagioclase composition with depth, so well expressed in well-differentiated intrusions, is poorly expressed here, where it is manifested by the increasing number of more basic varieties, with depth, which contain 60% to 70% of the anorthite component. Plagioclase with 50% to 60% An predominate in the upper levels. The most basic, as a rule, are plagioclase inclusions in pyroxene and olivine. In zoned crystals, the difference in anorthite content in peripheral segments and in nuclei does not exceed 10 per cent.

[1]Gabbro-diabazovaya intruziya khyukta v doline r. Imangdy (severo-zapadnaya chast' sibirskoy platformy).

Occurring alongside the continuously zoned crystals, in the gabbro-diabase in plagioclase with a well-defined discontinuous zonation emphasized by the presence of secondary minerals developed at the boundary of two zones. Some plagioclase crystals have as many as 6 to 8 zones. Throughout the intrusion, nearly all plagioclase crystals have been intensively altered by pelitization and sossuritization; in the vicinity of olivine grains, they are commonly decayed and replaced by serpentine and chlorite.

Pyroxene forms coarse xenomorphous grains containing poikolitic growths of plagioclase, most of which are represented by idiomorphous tablets and by less common corroded crystals. Pyroxene makes up from 22 to 24 per cent of the rock volume; its amount is greater in the upper part of the intrusion, reaching 44 per cent in some parts. Also common here are pyroxene crystals twinned at (100), with less common zoned crystals whose periphery always has an optical angle larger than the nucleus, suggesting a higher ferrous content in the peripheral parts of crystals.

Pyroxene is represented by augite whose composition is almost the same throughout the intrusion and ranges from $Wo_{38}En_{42}Fe_{20}$ to $Wo_{41}En_{38}Fe_{20}$ (after Hess, [3]). Its optical properties are characterized by its optic angle of 42° to 48°, the extinction angle $\gamma$ = 42° to 47°, and the refraction index $\beta$ = 1.692 and 1.695. Only in isolated augite crystals does the optic angle increase to +54°, with the corresponding composition of $Wo_{45}En_{40}Fe_{15}$. The augite crystals, as a rule, have a fresh aspect, with only a small part of their periphery replaced by drab-brown hornblende with a slight greenish cast. In peripheral parts of the intrusion, small biotite scales are developed on the hornblende. The hornblende contains much iron, whose presence accounts for the increase in the optic angle and refractive indices. The value of 2V for the hornblende described ranges from -68° to -76°, and the refractive index $\beta$ = 1.695.

Olivine is evenly distributed throughout gabbro-diabase of the intrusion, accounting for about 4 per cent of the rock volume, on the average; only at the base of the intrusion does its amount increase to 15 per cent. Most olivine grains are definitely xenoformous with relation to plagioclase; grains with rounded outlines occur in the lower part of the intrusion. The composition of olivine is almost the same throughout the intrusion, being characterized by high iron content, unlike the other intrusions of the area. The amount of fayalite in olivine ranges from 20 to 45 per cent, except for areas in contact with taxitic and pegmatitic gabbro-diorite where olivine contains 60 to 85 per cent $Fe_2SiO_4$.

The replacement of olivine by secondary minerals is most complete in the upper part of the intrusion, where relicts of the primary mineral are very rare; however, the number of unaltered grains is greater with depth, as a rule. There is much serpentine among secondary minerals developed on olivine, represented by a colorless or slightly colored antigorite, occasionally pleochroic from light-brown to greenish, with birefringence of 0.020, and an optic angle ranging from -23° to -39°. Most often, the antigorite replaces the central parts of grains, while talc and magnetite or a tabular mineral apparently associated with the chlorite group are developed along the periphery. The tabular mineral is drab-brown to greenish, is not pleochroic, and its birefringence does not exceed 0.007, as a rule, seldom attaining 0.020.

The optical properties of this mineral are extremely inconsistent; most commonly, it has a positive optic angle from 64° to 88°; in places it is optically negative, with 2V ranging from 6° to 24°. The refractive indices range from 1.580 to 1.613 (for $\gamma$).

On the whole, the ore mineral is represented by titanomagnetite forming large skeletal crystals which are generally overgrown with sphene. The lower parts of the intrusive section contain a poorly developed scattering of sulfides, chiefly of pyrrhotite, chalcopyrite, pentlandite, and pyrite.

One of the features of this intrusion is the high degree of metamorphism in gabbro-diabase. The numerous interstitial spaces between the plagioclase crystals are filled with platy and scaly to irregularly-radiated aggregates of actinolite, biotite, chlorite in association with quartz, carbonates, titanomagnetite, less commonly apatite, sphene, and pumpellyite. Biotite usually occurs in minute brown-green scales, mostly with regular hexagonal outlines, associated with a biotite pleochroic from green (along $\gamma$) to red-brown (along $\alpha$), which is developed near the grains of olivine and the ore mineral, by forming fringes about them and filling interstices in the skeletal crystals of titanomagnetite.

Quartz occurs in idiomorphic crystals corroded by actinolite, and in irregular grains. The acicular crystals of light-green actinolite form radial growths separated by biotite and thin-scaled chlorite, brown-green to light-green. In segments where the amount of interstitial quartz among these minerals increases sharply, the near-by plagioclase is strongly albitized and grown through with quartz, to form micropegmatitic intergrowths.

Apatite crystals form — along with elongated columnar bodies — short brown prisms. Sphene is rarely present, occurring in small irregular grains. All these minerals, including quartz, are developed evenly throughout the intrusive body, maintaining a more or less uniform association, throughout the section, from top to bottom.

The fine-grained gabbro segments consist of isometric to prismatic crystals of pyroxene filled-up with minute, irregular growths of plagioclase. The plagioclase also forms tabular crystals with the same degree of isomorphism as the pyroxene crystals. Plagioclase in gabbro has been fully replaced by secondary minerals, so that it is impossible to determine its composition. Prehnite is most commonly developed on plagioclase, in radial and tabular crystals. The gabbro pyroxene contains slightly more calcium than does the gabbro-diabase pyroxene, and can be included in the diopside-hedenbergite series. The higher calcium content in pyroxene brings about an increase in 2V, to +64° to 66°. The extinction angle $\gamma$ is 41° to 53°, the refractive index $\beta$ = 1.702.

Pyroxene predominates quantitatively in the rock; in individual segments with a prismatically granular texture, if forms monomineral accumulations where plagioclase is present only in poikilitic growths. Small cavities are not uncommon in gabbro, where they are filled partly to completely by finely fibrous zeolite, chlorite, and prehnite, which form chiefly spheroidal growths and radial aggregates.

In pegmatoid gabbro-diabase, coarse tabular plagioclase crystals, of andesine-labradorite composition, are strongly albitized and replaced by secondary minerals with quantitatively predominant sossurite and with smaller amounts of sericite and a pelitic substance. Some of the plagioclase crystals are overgrown with K-feldspar, apparently anorthoclase, with a low refractive index and a very fine twinning striation. K-feldspar also forms small irregular grains filling the space between plagioclase crystals; it is quite conspicuous in the rock matrix because of its brownish color caused by its intensive pelitization. K-feldspar is present with albite forming fresh-looking xenomorphic crystals.

There are prismatic, less commonly radial crystals of pumpellyite and elongated prismatic-columnar crystals of apatite present along with feldspars in interstitial spaces. Considerably less common among the plagioclase crystals is a thin-scale chlorite, at times forming spheroidal growths, and a greenish-brown biotite in small scales. Even less common are coarsely-crystalline carbonates with minute, haphazardly distributed acicular crystals of actinolite. Pumpellyite in pegmatoid gabbro-diabase makes up as much as 25 per cent of the rock volume and is distributed not only in interstitial spaces but also in fringes about the pyroxene crystals, or else as inclusions in anorthoclase growing on plagioclase. Characteristic of pumpellyite is its vivid-green color, a strong pleochroism, a variable sign of the elongation, and the strong dispersion of the ellipsoid axes. The extinction angle $\alpha$ = 22° to 40°; the refractive indices $\alpha$ = 1.706, $\gamma$ = 1.718. Pyroxene in pegmatoid gabbro-diabase forms coarse, xenomorphous crystals up to 2 centimeters in length. The ore mineral, accountfor as much as 9 per cent of the rock volume, is represented by titanomagnetite which forms large skeletal crystals, commonly in intergrowth with a small amount of sulfides. In most places, ore minerals are associated with a brown biotite; in interstitial spaces, they occur in small xenomorphic grains in K-feldspar.

Unevenly-grained taxitic gabbro-diabase is characterized by an ophitic structure, the absence of olivine, the intensive albitization of plagioclase, and by an extensive development (as much as 20 per cent of rock volume) of minerals filling the interstitial spaces; predominating quantitatively among these minerals are biotite in small scales, chlorite, and actinolite, with smaller amounts of quartz, carbonates, sphene, and apatite.

The gabbro-diabase varieties, recognized in the Khyukta intrusion, are very similar in chemical composition, which is in accordance with the above-mentioned lack of a clear differentiation in it. Table 1 shows that the composition of these gabbro-diabases is close to the world average for basalt, after R. Daly.

Thus, our rocks, despite the high degree of alteration, correspond to the composition of primary magma. As compared with the average composition of Siberian traprocks (after A.P. Lebedev), they have a higher alkali content (4.3% $K_2O$ + $Na_2O$ as against 2.9%), which is in accord with their somewhat more leucocratic composition. The melanocratic prismatically granular gabbros are characterized by a comparatively higher basicity, a higher magnesium and lime content, and a lower iron and alkali content. All this is in accord with the mineral composition of these rocks which are more than 95 per cent pyroxene of the diopside-hedenbergite series, containing poikolitic growths of plagioclase.

Considering the structure of the intrusion and the interrelationship of the several minerals in it, we come to the conclusion that magma began to crystallize before it filled up the intruded space. Intratelluric formations,

Table 1

| No. Sample | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | CaO | MgO | MnO | $Na_2O$ | $K_2O$ | $P_2O_5$ | $H_2O-$ | $H_2O+$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21/178 | 47,84 | 1,56 | 15,89 | 1,77 | 9,55 | 10,54 | 5,15 | 0,19 | 3,52 | 0,82 | 0,15 | 0,26 | 2,37 | 99,61 |
| 21/197 | 48,52 | 0,65 | 13,31 | 0,65 | 5,89 | 14,81 | 8,81 | 0,14 | 3,52 | 0,17 | 0,10 | 0,28 | 2,44 | 99,29 |
| 21/200 | 41,22 | 1,56 | 14,34 | 2,32 | 11,93 | 9,16 | 3,40 | 0,24 | 4,59 | 0,48 | 0,36 | 0,36 | 2,60 | 98,56 |
| 21/203 | 44,60 | 0,99 | 12,37 | 1,85 | 5,53 | 22,05 | 9,01 | 0,14 | 1,02 | 0,42 | 0,09 | 0,16 | 0,94 | 99,17 |
| 1 | 48,50 | 1,42 | 15,75 | 3,43 | 8,88 | 10,69 | 5,62 | 0,19 | 2,18 | 0,69 | — | 1,27 | 1,38 | 100,00 |
| 2 | 50.48 | 1,45 | 15,34 | 3,84 | 7,78 | 8,94 | 5,79 | 0,20 | 3,07 | 0,97 | 0,25 | — | 1,89 | 100,00 |
| 3 | 49,06 | 1,36 | 15,70 | 5,38 | 6,37 | 8,95 | 6,17 | 0,31 | 3,11 | 1,59 | 0,45 | — | 1,62 | 100,07 |

Numerical characteristics, after A.N. Zavaritskiy

| No. Sample | *a* | *c* | *b* | *S* | *f'* | *m'* | *c'* | *n* |
|---|---|---|---|---|---|---|---|---|
| 21/178 | 9,2 | 6,4 | 26,9 | 57,5 | 41,3 | 33,4 | 25,3 | 86,1 |
| 21/197 | 8,0 | 4,6 | 33,3 | 54,1 | 18,1 | 43,3 | 38,6 | 93,3 |
| 21/200 | 11,2 | 4,3 | 27,2 | 57,3 | 51,4 | 22,0 | 26,6 | 93,7 |
| 21/203 | 2,6 | 5,4 | 42,0 | 50,0 | 15,9 | 35,2 | 48,9 | 80,0 |
| 1 | 5,9 | 8,0 | 27,5 | 58,6 | 43,5 | 36,2 | 20,3 | 84,0 |
| 2 | 8,3 | 6,2 | 25,9 | 59,6 | 42,5 | 38,8 | 18,7 | 81,7 |
| 3 | 9,2 | 6,1 | 26,8 | 57,9 | 41,6 | 39,8 | 18,6 | 75,8 |

21/178— Medium-grained gabbro-diabase
21/197— fine-grained gabbro
21/200 — pegmatoid gabbro-diabase
21/203— melanocratic prismatically granular gabbro
1 — average composition of traprock (A.P. Lebedev)
2 — diabase (R. Daly)
3— basalt (R. Daly)

NOTE: Comma represents decimal point.

related to this period of crystallization, are represented by rounded olivine grains associated with the lower levels of the intrusion, where they participate in the building-up of olivine gabbro-diabase that forms a thin layer. Grains of earlier olivine are usually found in plagioclase and in inclusions within pyroxene. Thus, the bulk of rounded olivine grains appears to have settled prior to the pyroxene crystallization.

Interesting data on the rate of settling of olivine in liquid magma were obtained experimentally by some students. The settling process, according to these data, is fairly brief, the values of absolute velocity of the olivine settling ranging from 0.1 to 1 meter per hour.

The process of crystallization of magma in the intruded space began with the formation of plagioclase; only after the bulk of the plagioclase had crystallized out, did the crystallization of xenomorphic olivine and pyroxene begin, with the olivine somewhat anteceding the latter, although olivine grains, like those of pyroxene, are definitely isomorphic with relation to plagioclase. However, where olivine and pyroxene are in a direct contact, the olivine separates are seen to have the more idiomorphic outlines.

The crystallization proceeded under the conditions of a constantly disturbed equilibrium, which has led to the formation of zoned plagioclase and pyroxene crystals and to an extensive development of corrosion. The crystallization of basic minerals in gabbro-diabase was accompanied by a change in the composition of the liquid phase, with enrichment in iron, sodium, and the volatiles. This is also confirmed by data on the chemical composition of pegmatoid gabbro-diabases which are products of later crystallization phases. Related to these phases is the formation of such minerals as albite, anorthoclase, biotite, some titanomagnetite, apatite, and sphene. Somewhat later on, quartz, amphibole, chlorite, and carbonate were crystallized out. It is possible that their crystallization was connected with later hydrothermal stages.

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The All-Union Institute
of Mineral Raw Material,
Ministry of Geology and Conservation
of Mineral Wealth of the U.S.S.R.
Moscow

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# THE GOBI ALTAI EARTHQUAKE OF DECEMBER 4, 1957[1]

by

V.P. Solonenko

On December 4, 1957, at 3:39 A.M. Greenwich time, one of the strongest earthquake shocks in the world during the last half-century shook the Gobi Altai. Its intensity (M) was measured as 7.75 to 8.6 by stations in various countries; i.e., between 11 and 12 on the International scale. Although the estimate of the earthquake's intensity at 12 is exaggerated, it should be noted that its local effects corresponded to those which classify an earthquake as a "world catastrophe." These effects included the collapse of the Ikhe-Bogdo Mountains whose crest stands 3957 meters above sea level, the formation of a graben between the Bakhar-Ula and Tsetsen-Ula Mountains, the formation of a complex overthrust between the Ikhe-Bogdo and Baga-Bogdo Mountains, and the uplift of the Gobi Altai and easterly shift of 2.8 to 3.5 meters along a 250 kilometer stretch. Locally, the amount of displacement appears to approach tens of meters according to preliminary data from aerial negatives.

The unusual force of the earthquake is illustrated by the subsequent events: the main shock was followed by repeated strong shocks, with 120 shocks registered by seismic stations on December 4, 1957. The aftershocks have continued up to the present time (July, 1958). The Ikhe-Bogdo Mountains underwent intensive disintegration for two months, with frequent landslides observed as recently as April 1958.

It is natural that such an outstanding earthquake should have attracted general attention. It should be noted that because this highly active seismic region is sparsely populated, and because of the prompt assistance from the government of the Mongolian People's Republic, the casualties were few, and there was almost no material damage, despite the winter conditions.

For a preliminary study of the highly active seismic region of the Gobi Altai earthquake, the Committee of Science and Higher Education of the Mongolian People's Republic organized an expedition, authorizing the participation of Soviet experts.[2]

The highly active seismic province embraces the eastern part of the Bayan-Tsagan-Ula Range and the Gurban-Bogdo mountain chain which is the main easterly extension of the Mongolian Altai. The Bayan-Tsagan-Ula and Gurban-Bogdo chains, with their single mountain base, are morphologically divisible into separate mountain massifs (Fig. 1). The block development of this mountain chain appears to have been initiated at the close of the Mesozoic, and is still active.

The geology of the Gurban-Bogdo is very little known; as a matter of fact, there is even no small-scale geologic map of the region. The highly active seismic province is a Hercynian folded zone, with two structural stages clearly discernible within it. The lower stage is represented by strongly disturbed Paleozoic geosynclinal deposits, among which the following may be separated, according to the N.A. Marinov stratigraphic classification: lower Paleozoic schist-gneiss; a middle Paleozoic (Silurian and Devonian) sequence of sericite-chlorite quartz schist, with subordinate quartzite, effusives and tuff, limestone, and other rock types; and upper Paleozoic (Permian) effusives and tuff. The total thickness of Paleozoic deposits is approximately 10 kilometers. In many places they are cut by intrusions of granitoids, diorite, gabbro, and transitional rock types.

The upper structural level, developed during a platform stage of the region's history,

[1] Zemletryaseniye v gobiyskom altaye 4 Dekabrya 1957 g.

[2] Participating in the December 1957 – January 1958 expedition were I. Balzhinnyam, a seismologist at the Ulan-Bator station; O. Namnandorzh, a geographer; the geologists Sh. Tsebek, A.A. Treskov, N.A. Florensov, and the author. In June, 1958, the author carried out several aerial observations during the photographing of main faults formed on December 4, 1957.

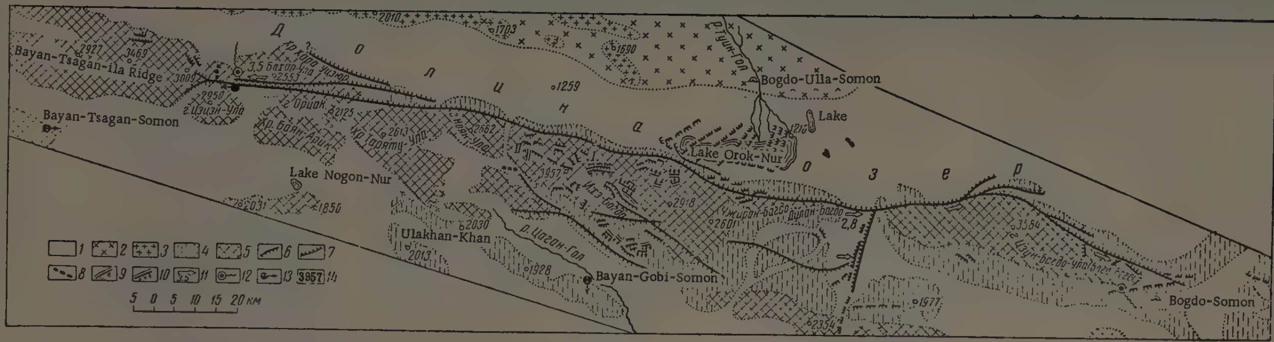


FIGURE 1. Diagrammatic map of the epicentral province of the Gobi Altai earthquake, December 4, 1957. Compiled by V.P. Solonenko, N.A. Florensov, and O. Namnandorzh, from aerial and ground observations December, 1957 and January, 1958; supplemented and detailed from aerial observations by V.P. Solonenko, in June, 1958.

1 -- Foredeeps, intramontane troughs and tectonic valleys; 2 -- base of the south extension of the Khangay Range; 3 -- remnant mountains of the base; 45 mountain massifs; 4 -- deposits of upper structural level, Mz - Cz; 5 -- formations of lower structural level; 6 -- faults (reverse-lateral; normal-lateral, etc.); 7 -- the Tormkhon thrust; 8 -- trenches apparently formed on sites of fissures connected with earlier earthquakes; 9 -- major landslides (I - the Bitutin; II - the Ulyasutay); 10 -- landslides; 11 -- the direction of lateral shift and its amount in meters; 12 -- larger streams formed during the earthquake; 13 -- direction of fall of buildings on December 4, 1957; 14 -- absolute elevations in meters (from the 1937 1:200,000 map, with the exception of the Ikhe-Bogdo and Lake Orok-Nur elevations, given on a recent topographic base).

is made up partly by lagoonal, chiefly continental, deposits, locally coal-bearing and bituminous, of Jurassic, Cretaceous, and Tertiary ages. Mesozoic and Cenozoic formations are located chiefly in intermontane troughs; however they are generally uplifted to a considerable height. Most geologists note the low degree of disturbance in Cretaceous and Tertiary deposits, except in the vicinity of faults where the dips reach 90°. The presence, in many places, of well defined en echelon folds in Mesozoic and Cenozoic formations was determined by our aerial observations in January and June of 1958.

The general picture of the onset of the Gobi Altai earthquake can be reconstructed from the stories of numerous eyewitnesses. About a minute before the main shock, there was a muted rumble heard from the direction of the mountain chain, and a slight tremor was felt. Then there was a crash heard from the direction of the Ikhe-Bogdo and Baga-Bogdo, reminiscent of a tremendous explosion (this from witnesses, 40, 60, and 75 kilometers away), whereupon immense dark clouds of dust arose above the mountain massifs, first enveloping the highest summits then spreading in all directions. The dust curtains, moving from the Baga-Bogdo and the Ikhe-Bogdo (a distance of about 120 kilometers) met and concealed the entire mountain chain, which is 200 to 230 kilometers long. Even beyond the mountain range, the sun was invisible or nearly so, behind the veil of dust; the visibility locally did not exceed 100 meters. The air was clear of dust only on the evening of December 6. No one saw just how the fissures were formed; the survivors in the vicinity of the fissures fainted and came to only after a few hours.

After the crash came the main shock which completely destroyed the district centers of Bayan-Tsagan-Ula, Bayan-Gobi, Ikhe-Bogdo, and Bayan-Leg. The earthquake affected an immense area: in Irkutsk, its intensity was recorded as 5, in Chita at 4 (the distances from the epicenter were 900 and 1300 kilometers, respectively); serious damage to structures occurred 300 to 325 kilometers away from the epicenter.

The instrumentally determined epicenter, as computed at the Irkutsk seismic station by K.V. Pshennikov, from 47 distant and 9 proximate stations, was located in the Bakhar-Ula mountain area. The epicentral zone was located between the two major orographic elements of the Gobi Altai: the Bayan-Tsagan-Ula and the Ikhe-Bogdo. It represents a depressed segment of the Gobi Altai where the range is broken up into numerous structural mountain blocks, arranged en echelon along the axis of a diagonal trough which cuts the range from the Dolina Ozer (Valley of Lakes) to the southern Naringol' trough. The en echelon system has a left lateral orientation — very characteristic for such structures developing along a fault.

This complex en echelon structure is of ancient origin, as is confirmed by the presence of Lower Cretaceous deposits in troughs, discovered between the Bakhar-Ula and Tsetsen-Ula mountains; it was active during Tertiary and Quaternary times. This is also suggested by the clean-cut geomorphic expression of the en echelon structures, the noticeable disturbance of Paleogene sediments and basalt flows. Basalt outcrops extend sublatitudinally and apparently are associated with deep faults.

Thus the epicentral zone belongs to one of the most shattered areas of the Gobi Altai, whose structure suggests unabating tectonic activity during late Mesozoic and Cenozoic time. Apparently it was here that the "ripping" of an old tectonic seam was initiated on December 4, 1957, and proceeded west to the Bayan-Tsagan Ula, but chiefly to the east, as far as the eastern terminal of the Baga-Bogdo Mountains. The exact pattern of fissures can be reconstructed from data derived from the aerial survey of the Pleistoseismic province and from seismo-geologic mapping; however, the magnitude of deformation can be estimated from preliminary observations. Major fissures have been traced for 683 kilometers. The total length of mapped short fissures (each less than 3 kilometers) is 170 to 185 kilometers. Many major fissures have not been traced over their entire length, while the haphazardly arranged fissures have not been taken into account at all, although locally they formed a dense network over an area of many square kilometers.

The largest break (Bogdo)[3] extends from the eastern edge of the Bayan-Tsagan-Ula Range, between the Bakhar-Ula and Tsetsen-Ula Mountains, and then along the northern slope of the Gurban-Bogdo to the eastern terminal of the Baga-Bogdo — a total of 274 kilometers. The main southern fissure is considerably shorter than the Bogdo break and is interrupted; it affects only the Ikhe-Bogdo massif — and not for its entire length. The total length of the souther fissure is about 106 kilometers. Deformations of the first order also include the Tormakhon thrust between Ikhe-Bogdo and Baga-Bogdo massifs. The faults cut a group of diversified rocks, including crystalline types.

Without providing a detailed description of

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[3] Dolinoozerskiy, according to A. Kh. Ivanov (see his Geologic Structure of the Mongolian People's Republic, Gostoptekhizdat, 1959). Russian Editor.

the fissures, we note only that they may be subdivided into three types, as follows:

1. Rejuvenated faults of ancient origin. These faults usually are lateral thrusts, changing to normal lateral faults, in isolated stretches, after passing through a short neutral zone. The initial epicentral zone witnessed the formation of another recent fault, parallel to the main one (Fig. 2). The main lateral thrust is a wing of the Bakhar graben which changes westward to a system of step-ladder normal faults. Here, compressive stresses gave place to tensile stresses, so that the fissures, usually closed, have gaps up to 19.15 meters wide with the en echelon tension fissures are best expressed (Fig. 3). The two principal and a number of secondary major fissures belong to this type.

2. The present tectonic deep-seated fractures, formed during the December 4, 1957 earthquake (Fig. 4). The most interesting among them is the Tormkhon fracture zone. It has been traced for 32 kilometers southwest of the Bogdo fault and it consists of three principal and a multitude of subsidiary faults. The main fracture is strongly expressed in relief (Fig. 5). As seen from above, from the northwest, the topography looks like an immense wave congealed in its advance toward the shore; seen from the southeast, it is a continuous escarpment, 1 to 12 meters high. A study of striations on the slickensides, in one area, has shown that the thrust was accompanied by a lateral shift to the northeast, offsetting the channels of temporary streams in the upthrown limb, for about one meter.

There is also a fissure here which cuts the Ikhe-Bogdo, in its central part, and which has caused the Bitutin and Ulyasutay landslides.

The direction and persistence of fractures of the first and second groups does not depend on relief and the character of rocks involved.

Peculiar, recent fractures are best described genetically, as "inert branches." They branch off the principal fractures where the latter bend, as if striving to maintain the original trend. Inasmuch as the "ripping-up" of the main tectonic suture went from west to east, an impression is created that the "inert

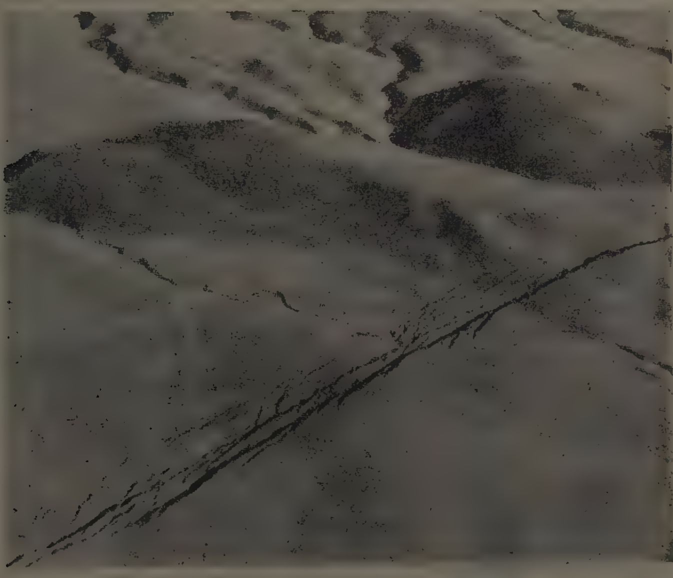

FIGURE 2. A segment of the main fissure where it branches.

The upper fissure is a rejuvenated ancient fracture; the lower fissure is a modern fracture. Note the well-defined system of plumate and diagonal fissures. Aerial photograph taken from an altitude of about 1500 meters. Photo by V. Solonenko, January 2, 1958.

FIGURE 3. South fissure of the Bakharsk graben.

Photo by V. Solonenko; January 4, 1958.

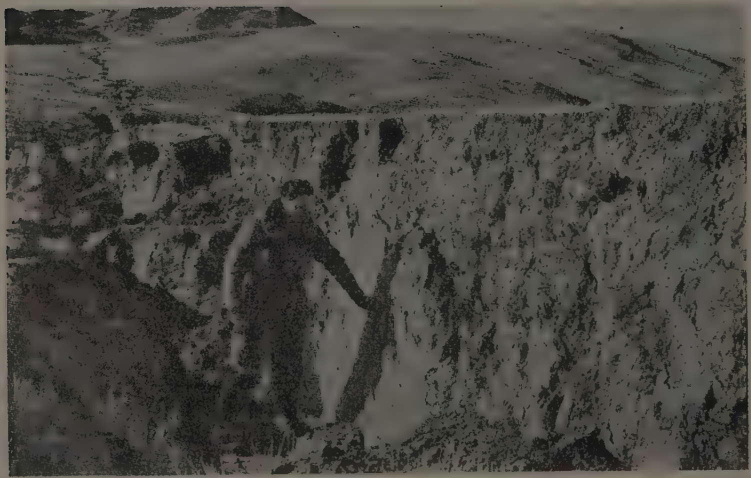

FIGURE 4. Fissure at the southern foothills of the Bakhar-Ula Range. The first seismo-tectonic fissure, cutting the original rocks, was found here.

Light color -- a slickenside formed on December 4, 1957.
Photo by V. Solonenko, January 3, 1958.

branches" are modern fractures formed as a result of the rocks splitting along an ancient fracture surface. Horizontal angles between the "inert branches" and the main-stem fault range from 10° to 30°, depending on the angle of veer. Such fractures are best expressed at the northern foothills of the Baga-Bogdo; the largest three are 9, 19, and 18 kilometers long, respectively.

3. The plumate fractures are generally short, commonly tens, rarely hundreds, of meters. Wherever observed, they branch off the main fractures, first bending in an arc, then running sub-parallel to the main fracture; their direction is always against the main shift, i.e., opposite on the two sides of the main fracture.

4. The subsidiary fractures run parallel to the main fracture of ancient origin and to modern deep-seated fractures. These breaks are discontinuous; the length of individual segments is measured in tens of meters to a few kilometers. They are rarely farther than 200 meters from the main fracture (but occasionally as far as 800 meters).

5. The collapse and landslide fractures formed in areas of great relief. A splitting-up of many divides and individual mountains occurred during the earthquake. Such fractures usually do not reach the foot of the highlands and are not tectonic fractures, in a narrow interpretation of this term. Their extent, however, is often very impressive: they attain several kilometers in length and 2 to 2.5 meters in width. Numerous landslides occurred along such fractures.

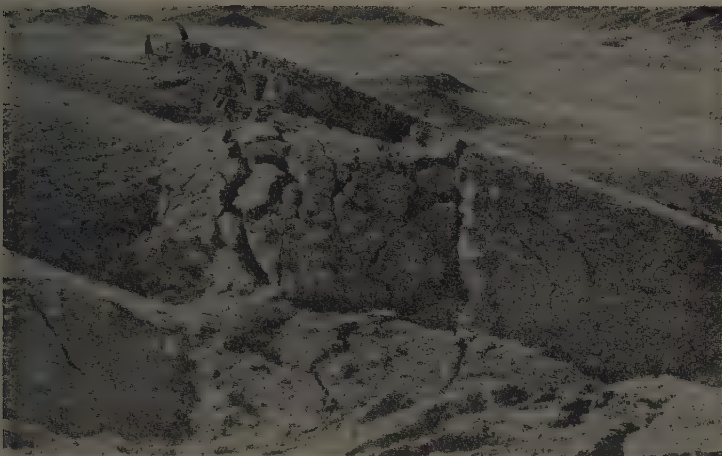

FIGURE 5. A rock wave at the Tormkhon fault.

Photo by V. Solonenko, January 5, 1958.

6. Gravity fractures, formed as a result of sliding and compaction of the ground. The fractures fissures along the south shore of Lake Orak-Nur appear to be of this type. The largest of them is 20 kilometers long; soon after the earthquake, it turned into a large trench, up to 6.5 meters wide, and the lakeside wing dropped 3.5 meters.

7. Hydraulic shock fractures which form a dense network in surface deposits in areas of a shallow water table. They cover sizable areas throughout the Valley of Lakes, in river valleys, and in lowlands and dry creek beds.

The overall kinematic picture of displacements shapes up as follows: the Gurban-Bogdo mountain chain was uplifted and displaced to the east. The magnitude of the horizontal and vertical components is different in different parts of the mountain system. It is the greatest along the northern fracture where the vertical displacement is from 0.8 to 12 meters. The Bogdo fault is vertical along most of its extent; in its eastern part, however, as

revealed by our aerial observations and by early aerial photographs taken in June of 1958, it dips to the south, under the Baga-Bogdo massif, at an angle of about 60° to 70°. The displacement was accompanied by a twist, in both the horizontal and the vertical planes: the northern edge of the mountain chain was displaced farther to the east than the southern. In addition, the Ikhe-Bogdo massif was displaced farther east than the Baga-Bogdo; this has brought about the Torm-khon thrust. The magnitude of horizontal displacement, as measured from the offset of roads and trails, is 2.8 to 3.5 meters; an offset of about 10 meters in dry creek beds was discovered in one area from aerial photographs.[4]

Most deformed was the Ikhe-Bogdo massif, which is nearly surrounded by major faults and cut by numerous secondary faults. The gigantic landslides in the Bituti-Ama and Ulyasutay canyons are associated with the largest of them. The Bituti-Ama and Ulyasutay canyons are associated with the largest of them. The Bitutin landslide is about six kilometers long, with the height of the collapsed mountain side of crystalline schist and granite reaching 300 to 350 meters; and the volume of the sliderock at least 200 million cubic meters. As a result, the Bituti-Ama canyon was dammed to a considerable height, and a lake formed behind the dam.

Judging from the irregular deformation in the Gurban-Bogdo mountain chain, it may be assumed that the stresses in it have not been completely relaxed, by the December 4 earthquake. It is possible that this deformation has created new stresses in individual areas of the Pleistoseismic province. The greatest stress prevail in the saddle between the Ikhe-Bogdo and the Baga-Bogdo Mountains and in the western part of the Pleistseismic province (the eastern terminal of the Bayan-Tsagan-Ula Range and the Bakhar area), where epicenters of the strongest aftershocks, reaching 8 or 9 points are to be anticipated.

[4] **Preliminary determination from negatives of aerial photographs of the Bogdo fault, taken on June 28, 1958, at a scale of approximately 1:10,000. The displacement is given everywhere without considering the elastic bend deformations which may be sizable. For instance, we measured a throw of 1.5 to 2.5 meters for the Khara-Utszyur Creek, with bending of 2 to 2.5 meters, for the uplifted limb, over a distance of 100 meters.**

The Geology Institute,
East Siberian Affiliate,
Siberian section
of the Academy of Sciences, U.S.S.R.
Irkutsk

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# CONDITIONS OF DISTRIBUTION OF SIDERITE ORES THROUGHOUT THE HOST ROCKS OF THE BAKAL' GROUP OF ORE DEPOSITS, SOUTHERN URALS[1]

by

Z.M. Starostina

On the basis of her study of the occurrence of the Bakal' siderite ores, throughout the section and areally, the author comes to the conclusion that these ore deposits are associated with definite facial conditions during their sedimentary origin.

According to the author's observations, the richest sideritic facies follow a clean-cut latitudinal trend in the area of the Bakal' group of ore deposits. The overall ore-bearing zone trends to the northeast. This latitudinal trend does not agree with the northeastern trend of the present tectonic structures and appears to be connected instead with the tectonic development of the Ural foredeep as a whole, where it joins the Ufa plateau.

* * * * *

## I. INTRODUCTION

The study of the Bakal' group of siderite ore deposits was carried out in connection with a project of the Geological Institute, Academy of Sciences, U.S.S.R., for a study of Proterozoic ferruginous ore deposits in geosynclinal provinces.

The administration of the Bakal' Geologic Exploration Group and of the Bakal' Ore Deposits have put at our disposal their maps, reports, and drilling data. This enabled us to compile the enclosed maps showing the distribution of siderite deposits in enclosing rocks at each horizon. The author expresses her gratitude to V.K. Golovchenko, N.V. Grinshteyn, O.P. Segeyev, and A. Ya. Panov.

The Bakal' group of ferruginous ore deposits in the Southern Urals is located within the Uralian foredeep, where the latter rises toward the Ufa plateau, directly in the area of northern closure of the southeastern branch of the Inzer synclinorium [20].

The eastern limb of the Bakal' syncline is represented by the Suka Range; the western limb by the Shuyda Range. Smaller structures are located within it, such as the Irkuskan-Suka, Irkuskan-Bulandikhin, and the Petlinsk synclines; and the Irkuskan, Balundikhin, and Maloshuydinsk anticlines. These structures are marked by a northeastern trend, a steep dip of the northwestern anticlinal limbs, the southwesterly pitch of the structural axes, and by the presence of reverse faults, with fault planes dipping to the southeast.

Within the northern termination of the Inzer synclinorium, the Tartash series of lower Proterozoic age, represented by gneiss, micaceous quartzite, metashale, ferruginous quartzite, and jaspilite, is overlain by a great angular unconformity by the Lower Riphean Burzyansk series (the lower ferruginous series), with the Yurmatinsk series (upper ferruginous series) above it, and the Karatau series above that. The section is culminated by the Ashinsk series.

The Bakal' formation, which carries siderite deposits within the area under study, belongs to the Riphean Burzyansk series.

## II. STRATIGRAPHY

The M.I. Garan' stratigraphic section [2] for the Bakal'-Satkin area is still the standard in the study of the Bakal' ferruginous deposits. According to it, the Bakal' formation, in area of the ore deposit, is subdivided as follows (reading upward):

a) the Makarovsk member represented by chlorite-sericite-quartz phyllite-like metashale;

b) the Berzovsk member of algal limestone;

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[1] Ob usloviyakh razmeshcheniya sideritovykh rud vo vmeshchyushchikh porodakh bakal'skoy gruppy mestorozhdeniy (yuzhnyy ural).

c) the Irkusan member of mica-chert pelitic meta-shale with sandstone intercalations;

d) the lower Bakal' ore-bearing member of dolomite, limestone and siderite, with intercalations of meta-shale and magnesite lenses;

e) the middle Bakal' member characterized by calcareous shale, meta-shale, and sandy shale with subordinate argillaceous limestone;

f) upper Bakal' member, also ore-bearing, represented by stromatolitic limestone, dolomite, dolomitic limestone with intercalations of meta-shale, and siderite;

g) the Bulandikhin member of shale, sericite-quartz meta-shale, and sericitic phyllite-like meta-shale.

They are overlain, with a sharp erosional break, by quartzite of the Zigal'ga series.

This classification holds true on the whole for the entire region. But, deep drilling by the Bakal' Exploration Group revealed the presence of new ore deposits in that area and refined to a considerable extent our knowledge of the upper part of the Bakal' formation. According to these data, the middle Bakal' member includes not only the shale with subordinate argillaceous limestone but also the stromatolitic limestone and dolomite of the M.I. Garan' upper Bakal' member, the overlying meta-shale, the massive limestone above them, and the shale member penetrated in the southern part of Bulandikha Mountain.

Also belonging to the upper Bakal' member are rocks found in cuts of the Ob"yedinennoye, Bulandikha, and Vostochnoye mines, where they are represented at the base by phyllite-carbonate rocks having a worm-like texture, locally mineralized; they are overlain by tough limestone and dolomite with ore deposits; these rocks are followed by sandy shale with intercalations of stromatolitic limestone. According to the exploration data, the section is topped by the Bulandikhin member of sandy shale with a marker bed of quartzite and lenticular stromatolitic bioherms.

Thus the ore-bearing member of the Bulandikha, Ob"yedinennoye, and Vostochnoye mines is not a stratigraphic equivalent of the Gayevskaya Yama and the Sideritnyy quarry deposits, as formerly believed, but rather a new and higher ore-bearing member in the Bakal' section. These stratigraphic differentiations and correlations seem to be very convincing; for this reason we have adopted them in our stratigraphic exposition, with a few corrections in the nomenclature and indexing—because, strictly speaking, the entire Bakal' formation in the area of the Bakal' ore deposits is a discrete carbonate-schist sequence which changes in the south to a thick, barely differentiable section, and in the north to a carbonate section.

The Bakal' area is located in the transition zone from a carbonate facies of the Bakal' formation to an argillaceous facies; this has controlled the alternation of argillaceous and carbonate members which are of about the same stratigraphic value. For this reason, it is probably more proper to affix the index designation "Bak" to the entire Bakal' formation and to designate its several carbonate and shale members as 1, 2, 3, 4, etc., (Table 1).

## 1. Bakal' formation, Bak

As mentioned above, the Bakal' formation consists of an alternation of carbonate rocks and shale. The carbonate members are ore-bearing and undergo definite facies changes within the area; for this reason, they are the main object of our study.

The shales that separate them are marked by a similarity in their composition, being represented by dark gray to almost black pelitic to silty, carbonaceous, chloritic-sericitic, at times cherty to carbonate, thin-bedded varieties, occasionally like phyllite. Locally they carry abundant inclusions of iron and pyrite hydroxides, in veinlets and clots.

The thickest is the lower, First shale (Makarovsk) member which reaches 400 meters in thickness, according to M.I. Garan'. In the northern part of the area, it carries lenticular deposits of brown ferruginous rock. The Second shale member (Irkuskan) is 200 to 300 meters thick. Higher up, because of the general increase in the carbonate content, the shale members grow thinner, down to 100 and even as little as 10 meters. Because of a southerly wedging out of carbonate rocks, the thickness of shale members increases in that direction.

Close to the erosional surface, the shales acquire a mottled coloring; at their contact with the overlying quartzite, they become a conglomeration of angular fragments of motley mudstone with an argillaceous to quartz cement (the ancient weathered crust).

Lower carbonate member (Berezovsk), $Bak_2$. Shales of the Makarovsk member are conformably overlain by carbonate rocks penetrated in deep boreholes along the southern boundary of the Irkuskan Range and in the OGPU mine (Fig. 1).

In the course of reconnaissance work of

Table 1

Stratigraphic differentiation of the Bakal' formation by members

<table>
<tr><th>M.I. Garan': Malaya Shuyda and Irkuskan Ranges</th><th>Bakal' Geologic Exploration Group</th><th>Z.M. Starostina</th></tr>
<tr><td colspan="3">Zigal'ga formation</td></tr>
<tr><td></td><td>Members<br>Bulandikhin</td><td>Sixth shale, Bak$_{11}$</td></tr>
<tr><td></td><td>Upper Bakal'</td><td>Upper carbonate, Bak$_{10}$</td></tr>
<tr><td rowspan="3">Bulandikhin</td><td rowspan="5">Middle Bakal'</td><td>Fifth shale, Bak$_9$</td></tr>
<tr><td>Limestone, Bak$_8$</td></tr>
<tr><td>Fourth shale, Bak$_7$</td></tr>
<tr><td>Upper Bakal'</td><td>Stromatolitic ore-bearing, Bak$_6$</td></tr>
<tr><td>Middle Bakal'</td><td>Third shale, Bak$_5$</td></tr>
<tr><td>Lower Bakal'</td><td>Lower Bakal'</td><td>Magnesite-carrying, dolomitic, ore-bearing, Bak$_4$</td></tr>
<tr><td>Irkuskan</td><td>Irkuskan</td><td>Second shale, Bak$_3$</td></tr>
<tr><td>Berezovsk</td><td>Berezovsk</td><td>Lower carbonate, Bak$_2$</td></tr>
<tr><td>Makarovsk</td><td>Makarovsk</td><td>First shale, Bak$_1$</td></tr>
</table>

recent years, an ore-bearing carbonate member has been discovered in the northern part of the Malaya Shuyda Range (Novobakal'skiy district); the stratigraphic position of this unit was not clear. First, these rocks were correlated with the lower Bakal' member; later on, the idea dawned that they might be correlative with the Berezovaya Mountain limestone (Berezovsk member of M.I. Garan') [7, 16]. A correlation of sections from deep boreholes in OGPU mine, the Shikhanskiy and Novobakal'skiy districts, with the southern part of the Bulandikha Range (see Fig. 1) convinces us that these rocks are not correlative with the lower Bakal' member but rather are an independent carbonate ore-bearing member correlative with the Berezovsk. In the middle part of the Malaya Shuyda Range, within cross sections 3 through 7 (the exploratory cross-section lines run NW-SE, and are designated on the maps by numerals), this member, 50 to 60 meters thick, is represented by an alternation of thin beds of white, fine-grained siderite, a dark argillaceous dolomite, and black carbonaceous silty pelitic material. To the northeast along the Malaya Shuyda Range, the amount of carbonaceous-argillaceous material decreases, with gray to yellowish, at times banded, siderite varieties in the ascendence. The banded effect is caused by the finest alternation of a carbonaceous-argillaceous, fine-grained ferruginous dolomite and a coarser-grained siderite, having a yellowish ting ("cherty" siderite). A so-called wormy texture has been observed in some varieties. The siderite section contains rare intercalations of silty-pelitic shale and light-gray medium-grained dolomite.

This carbonate member becomes exposed because of the general rise of the axis of the Maloshyudinsk anticline, from south to north (Fig. 2). Here, in the oxidation zone, siderite is altered to brown iron ore (the Novobakal'sk deposit) which is replaced, still farther north, by a dolomite layer 70 meters thick. Farther north, the latter changes to limestone with subordinate dolomite, total thickness as much as 250 meters.

The same sequence has been observed northwest of the Malaya Shuyda Range (Fig. 2): siderite wedges out giving place to dolomite, then to limestone, up to 125 meters thick.

On the southeastern slope of the Malaya Shuyda Range, the thickness of this member is diminished; brown ferruginous rocks which replace the siderite wedge out, and argillaceous intercalations appear with the dolomite.

In the central part of the OGPU mine, to the southwest, these rocks are represented

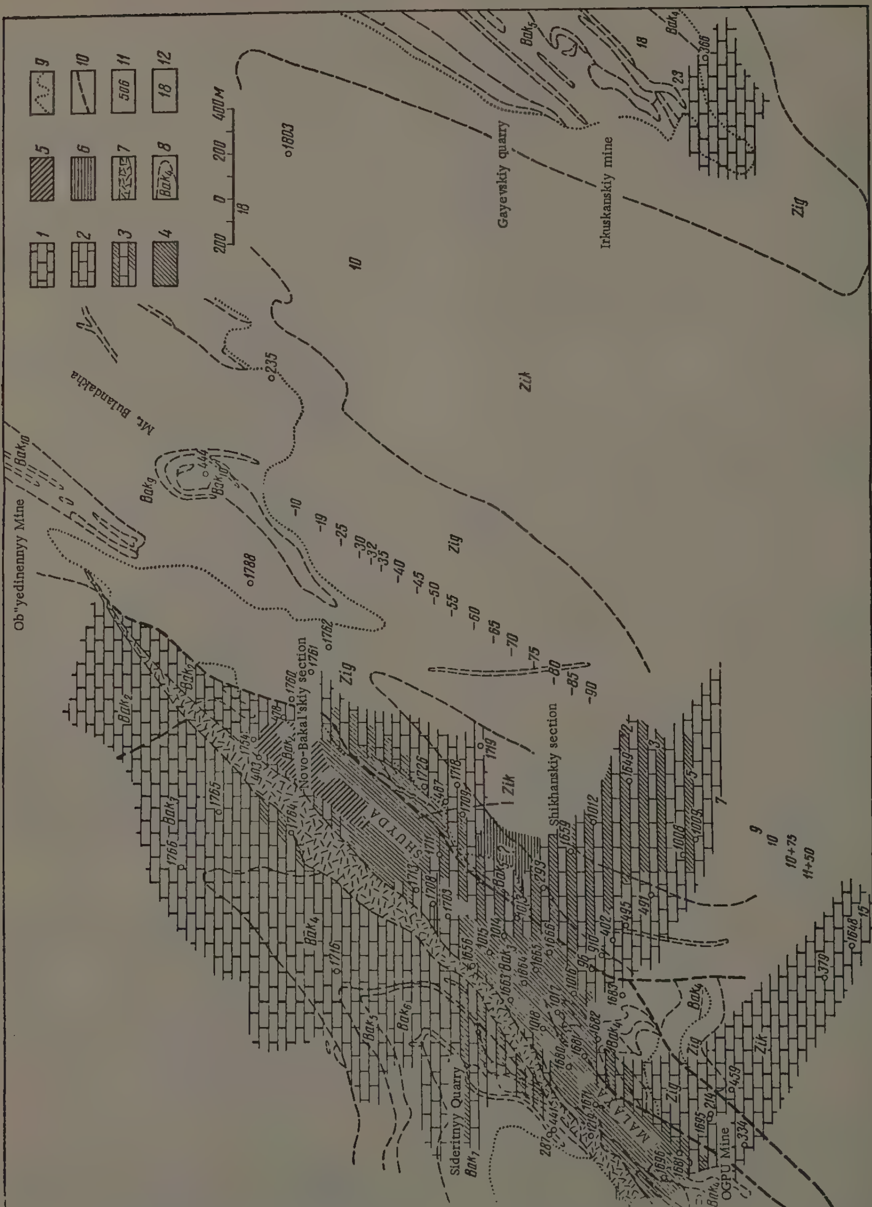

FIGURE 1. Distribution of siderite in member $Bak_2$, of the Bakal' ferruginous ore deposit. Compiled by Z.M. Starostina. Geologic map by Yu.S. Solov'yev, V.A. Knyazev, and Yu.A. Davydenko, under the direction of Professor A.Ye. Malakhov. The map has been refined as a result of work by the Bakal' Geologic Exploration Group, 1950-1957.

1 -- Limestone; 2 -- dolomite; 3 -- dolomite with siderite beds; 4 -- siderite with dolomite beds; 5 -- brown ferruginous rock; 6 -- shale; 7 -- diabase dikes; 8 -- stratigraphic boundaries; 9 -- boundary of pre-Zigal'ga erosion; 10 -- faults; 11 -- borehole numbers; 12 -- numbers of stratigraphic section.

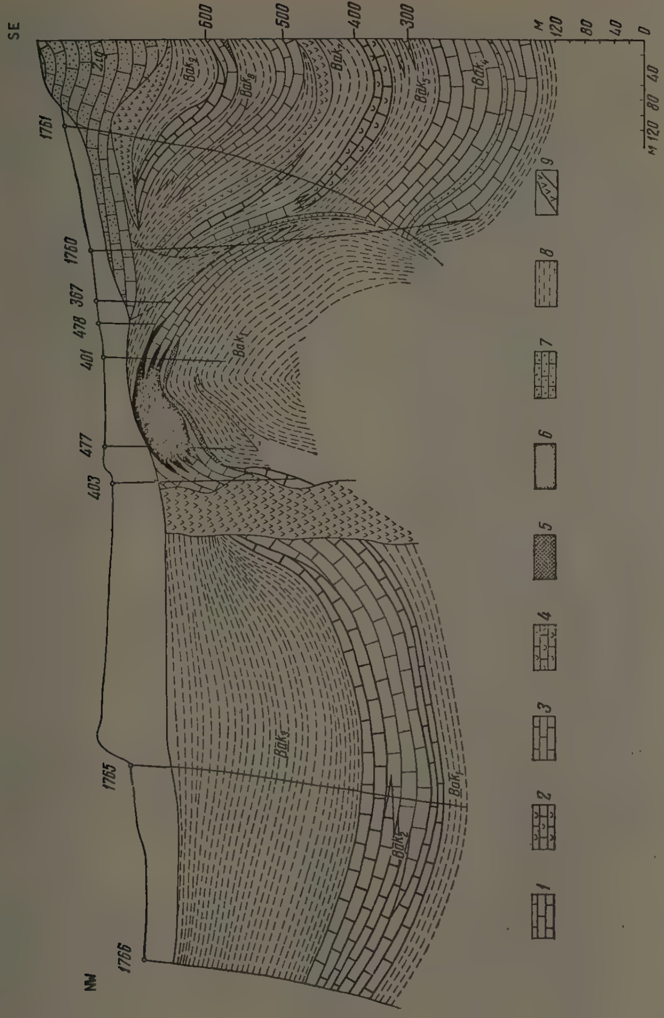


FIGURE 2. Cross section 35-35. Compiled by the Bakal' Geologic Exploration Group.

1 -- Limestone; 2 -- limestones with stromatoliths; 3 -- dolomite; 4 -- dolomite with stromatoliths; 5 -- siderite; 6 -- brown ferruginous ores; 7 -- quartzite; 8 -- shale; 9 -- diabase.

by black, strongly argillaceous, bedded siderite, 14 to 15 meters thick (borehole 1681). Farther southeast, the siderite is replaced by dolomite which changes to limestone, farther on. In borehole 1648, the limestone is not over 22 meters thick (Fig. 3). In borehole 1649, to the north, this member is represented by an alternation of dolomite and siderite, over 70 meters thick.

In the Irkuskan Range, the same stratigraphic position is occupied by a 200 meter thick sequence of dark limestone correlated with the siderite-bearing carbonate member of the Malaya Shuyda Range but truly correlative probably with its northern limestone facies.

The marked decrease in the thickness of the lower carbonate member (down to 14 or 15 meters), from north and northwest to southwest and south, accompanied by a regular rise in the amount of carbonaceous-argillaceous material in the same direction, suggests a complete replacement of the lower carbonate member by argillaceous deposits in that direction. The formation of a siderite deposit occurred in the peripheral zone of carbonate

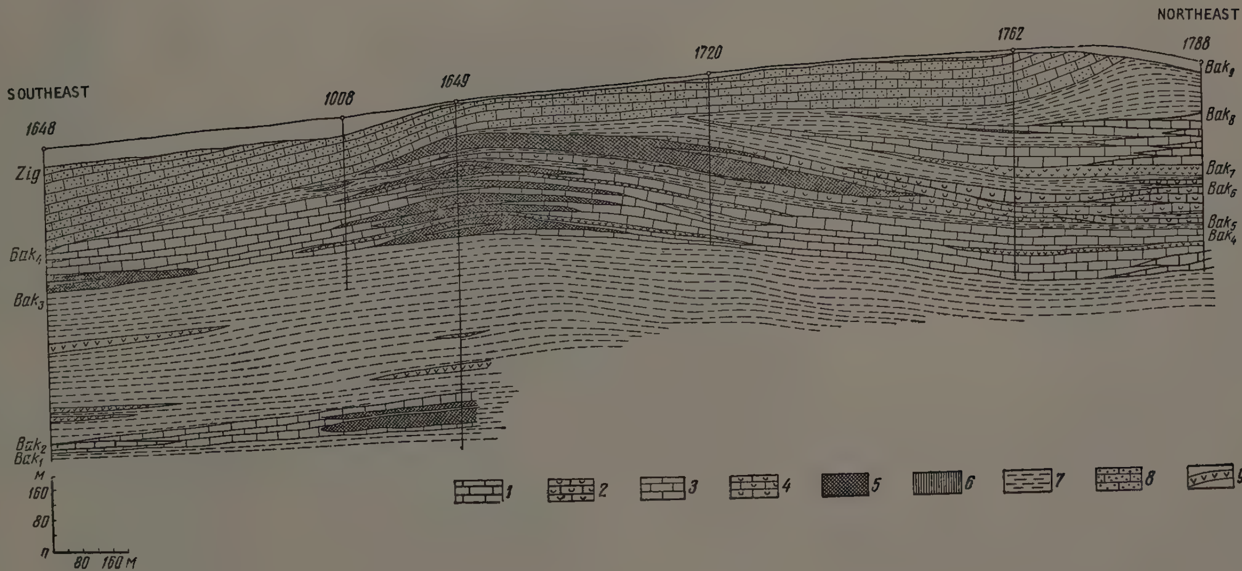


FIGURE 3. Cross section I-I. Compiled by Z.M. Starostina.

1 -- Limestone; 2 -- limestone with stromatoliths; 3 -- dolomite; 4 -- dolomite with stromatoliths; 5 -- siderite; 6 -- magnesite; 7 -- shale; 8 -- quartzite; 8 -- diabase.

rocks, near the zone of transition to argillaceous facies. The presence of the Malaya Shuyda anticlinal structure apparently was the controlling factor in the distribution of siderite, whose thickest lenticular deposit is located in the crest of the fold, trending in a northeast direction to the axis of the fold, and wedging out to the north and northwest, changing first to dolomite then to limestone.

Magnesite dolomite (lower Bakal') member $Bak_4$. Separated by shales from the underlying lower carbonate member, is a member of thick-bedded, less commonly massive, white to gray dolomite, containing lentils of carbonate-carbonaceous shale, small lenses of magnesite, and beds of sideritic dolomite and siderite, of various thickness. When occurring in the zone of oxidation the siderite is altered to brown iron ore.

Dolomite is represented by fine-grained, locally coarse-grained, varieties carrying clastic and carbonaceous material which is distributed either in fine dispersion, in the space between grains, or at the boundary between them.

Pyrite is disseminated throughout the dolomite. As a rule, dolomite is ferruginous (Fe content up to 5 per cent), less commonly magnesial, often carrying a small amount of manganese (usually not over 1 per cent).

Siderite consists of fine-grained varieties, gray to light gray, rarely dark gray. Like the dolomite, it carries carbonaceous and argillaceous material which determines its color. In banded varieties, there is an alternation of thin laminae of cherty siderite and of siderite enriched in fine carbonaceous matter.

The small magnesite lenses, not over 15 meters thick, are represented by a medium- to coarse-grained, light gray rock carrying a considerable amount of carbonaceous material; as in siderite, the latter is distributed in fine fringes about the grains. These varieties differ in their higher content of $CaCO_3$ and iron from the Satkino magnesite; the amount of the latter reaches 10 per cent.

The intervening shale in this member is little different from those in the underlying member. It consists of the same carbonaceous, pelitic, occasionally silty meta-shale with a siliceous-micaceous matrix.

Southwest of the OGPU mine, in the axial part of the Malaya Shuyda Range (Fig. 4), this carbonate member is represented chiefly by dolomite, 80 to 100 meters thick. Over a distance of 250 to 300 meters southeast of there, they first thin down rapidly, to 40 or 60 meters, then wedge out and become replaced by shale; the bulk of ore-bearing beds is located to the southeast, in the wedge-out zone. The ore-bearing beds, here, alternate with shale.

To the west, in the Petlinskaya syncline, the Shuydinsk ore deposit area, the mineralization of this member also decreases; to the southwest, thin beds of siderite and brown ferruginous rocks (Shuyda I) gradually change to lean siderite (Shuyda II) and then to ferruginous dolomite carrying 10 to 15 per cent iron (Shuyda III).

To the west, in the Shuyda Srednyaya area, siderite-free dolomite is interbedded with shale.

To the northeast, within the Maloshuydinsk anticline, the ore-bearing member $Bak_4$ gradually rises to the surface and siderite is fully replaced by brown iron ores which are worked in the OGPU mine. The ore-bearing part of the section in the anticlinal crest also contains shale beds (Fig. 5). Northeast of the mine, in the axial part of the Maloshuydinsk anticline, these deposits have been eroded away, while east of the OGPU mine on the southeastern limb of the fold and in the adjoining syncline, the thickness of this carbonate member increases to 115 or 160 meters; its main components are dolomite with or without siderite beds (boreholes 1648, 1009, and 1700).

In the Shikhansk area, where the member thickens to 185 meters, (boreholes 1003, 1012, 1649), siderite also is on the ascendency, attaining an overall thickness of 100 meters or more (Fig. 3). Farther northeast, north, and northwest, siderite gradually wedges out.

The sizable deposits of siderite, penetrated by boreholes in the Shikhansk area, are a sort of extension of the OGPU deposit and are in turn connected with the Irkuskan deposit to the east along the strike of this nearly longitudinal zone of higher siderite content.

This ore-bearing sequence of magnesite-carrying dolomite is most accessible for study in the Irkuskan Range. In the Tsentral'nyy quarry, the entire dolomitic section is well exposed, with its thick beds of siderite, oxidized or semi-oxidized, interbedded with lentils of shale and pockets of secondary brown iron ore. A local feature of this section is the presence at its base of stromatoliths and clastic dolomite. On the northwestern slope of the Irkuskan Range, the thickness of magnesite-carrying dolomite reaches 120 to 140 meters; in an adjacent syncline to northwest, the siderite wedges out and is fully replaced by dolomite.

On the southeastern slope of that range,

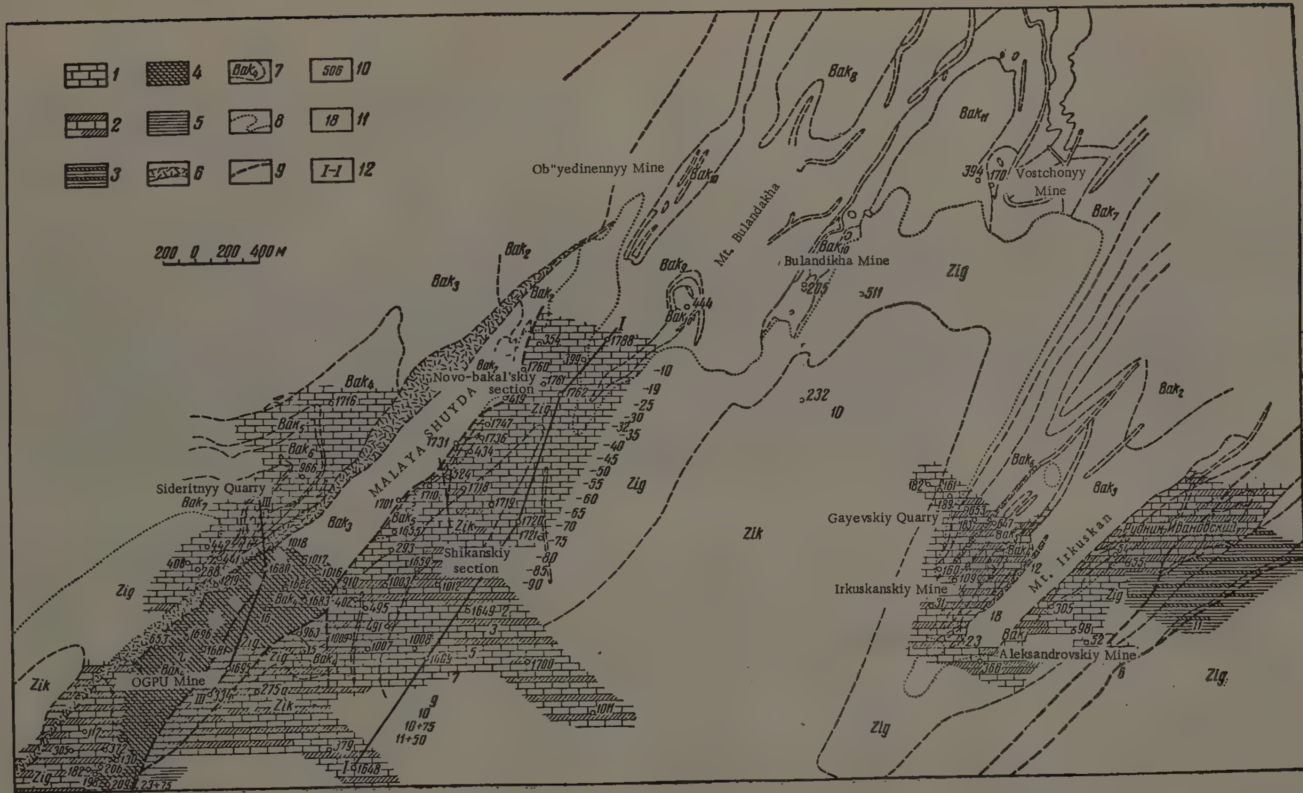


FIGURE 4. Distribution of siderite in member $Bak_4$, the Bakal' iron ore deposit. Compiled by Z.M. Starostina. Geologic map by Yu.S. Solov'yev, V.A. Knyazev, and Yu.A. Davydenko, under the direction of Professor A.Ye. Malakhov. The map has been refined from the results of work by the Bakal' Geologic Exploration Group, 1950-1957.

1 -- Dolomite; 2 -- dolomite with intercalations of siderite and sideritic dolomite; 3 -- shale interbedded with brown iron ore; 4 -- shale with thick beds of brown iron ore; 5 -- shale; 6 -- diabase dikes; 7 -- stratigraphic boundaries; 8 -- boundary of pre-Zigal'ga erosion; 9 -- faults; 10 -- borehole numbers; 11 -- cross-section numbers; 12 -- cross-section lines.

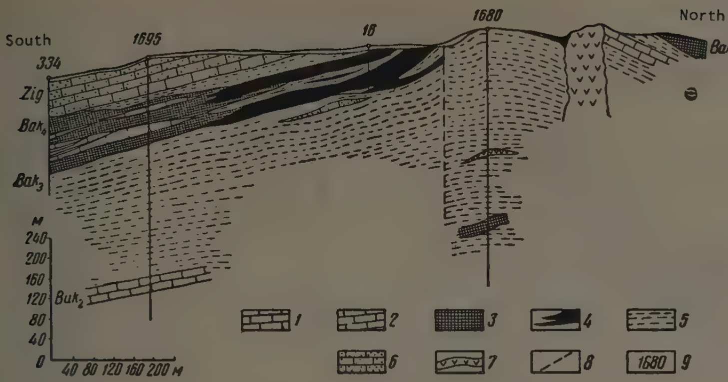


FIGURE 5. Cross section III-III. Compiled by Z.M. Starostina.

1 -- Limestone; 2 -- dolomite; 3 -- siderite; 4 -- brown iron ore; 5 -- shale; 6 -- quartzite; 7 -- diabase; 8 -- fault lines; 9 -- borehole numbers.

the thickness of the ore-bearing member is cut down, and it changes over a short distance to barren dolomite. (Aleksandrovsk mine, cross-sections 6, 7; cross-section 11, to the north).

On a continuation of the same zone of ore-bearing dolomite, farther north, is the Ivanivskiy mine, where the ore-bearing carbonate member is very thin. Less known are the ore exposures still farther east (Krepkaya Yama, Nizhneokhryanaya Yama), where they are associated with shale. The true relationship is camouflaged here by faulting.

The reduction in the thickness of magnesite-carrying ore-bearing dolomite, south and southwest of the OGPU mine and on the southeastern slope of Irkuskan Range, especially well expressed within the Ivanovskoye mine, along with evidence of shallow-water conditions during the deposition of dolomite in the Tsentral'nyy quarry section, the Irkuskan deposit (stromatoliths, clastic textures, evidence of reworking), also suggests that this siderite originated in peripheral zones of carbonate sediments. This has also been noted for siderite of the lower carbonate member.

The stromatolitic carbonate member (upper Bakal') $Bak_6$ is best exposed and most accessible for study on the northwestern limb of the southern terminus of the Irkuskan Range (Gayevskiy quarry, Fig. 6). Very characteristic of this member is the presence of stromatoliths which make up nearly all of it.

This member is represented in the quarries by light to light-gray recrystallized stromatolithic dolomite, dolomitic limestone, and siderite, with small secretions of iron hydroxides and the addition of argillaceous and carbonaceous material; as a result of recrystallization, the latter forms thin vein-like accumulations and fringes about grains. A considerable part of this section consists of calcareous dolomite and limestone, and locally shale and carbonate shale.

On the northwestern slope of the Malaya Shuyda Range, south of the Sideritnyy quarry, the stromatolitic member is not over 40 meters thick, increasing to 80 meters in the north, with a well-defined area of higher sideritization. An example is the Sideritnyy quarry section, where a siderite deposit as great as 60 meters thick has been exposed. To the northwest, and at the northeastern edge of the quarry, siderite beds grow thinner and are replaced by dolomite which, in turn, changes to limestone, a short distance to the northeast (borehole 966, Fig. 6).

Thick beds of siderite (up to 60 meters thick) have been uncovered also on the southeastern anticlinal limb in the Shikhansk area and to the north (boreholes 1012, 1720, 1772; Fig. 3). In borehole 1762, the stromatolitic member, now siderite-free, is made up chiefly of dolomite which grows thicker farther to the north and changes to limestone (borehole 1788).

South of the Shikhansk area (boreholes 1006, 1008), siderite wedges out gradually,

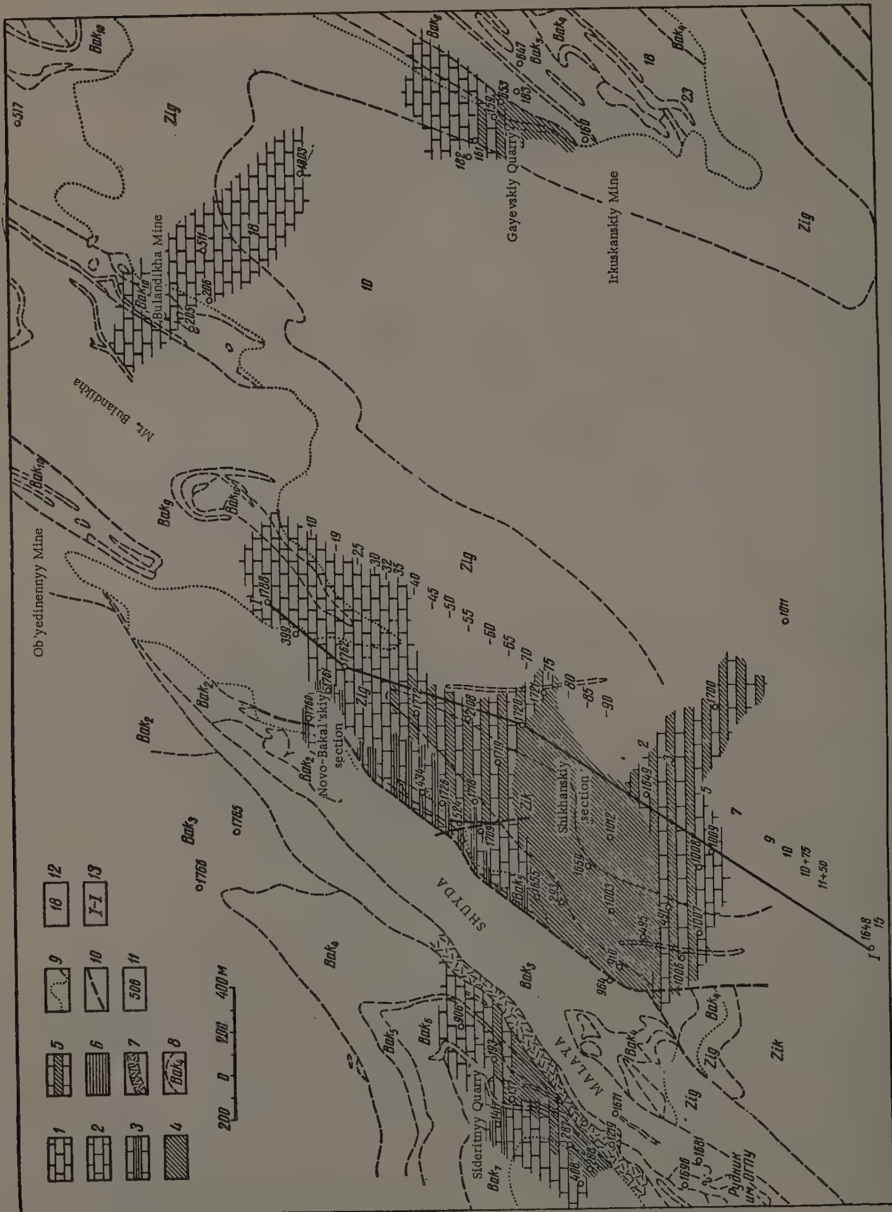

FIGURE 6. Distribution of siderite in member Bak6, Bakal' iron ore deposit. Compiled by Z.M. Starostina. Geologic map by Yu.S. Solov'yev, V.A. Knyazev, and Yu.A. Davydenko, under the direction of Professor A.Ye. Malakhov. The map has been refined from the results of work by the Bakal' Geologic Exploration Group, 1950-1957.

1 -- Limestone; 2 -- dolomite; 3 -- dolomite interbedded with shale; 4 -- siderite; 5 -- dolomite interbedded with siderite; 6 -- shale; 7 -- diabase dikes; 8 -- stratigraphic boundaries; 9 -- boundary of pre-Zigal'ga erosion; 10 -- fault lines; 11 -- borehole numbers; 12 -- cross-section numbers; 13 -- cross-section lines.

being replaced by dolomite.

Very similar to the Sideritnyy quarry section is that of the Gayevskiy quarry. Here, thick stromatolitic siderite beds dip steeply to the northwest and change to dolomite in the same direction. The same phenomenon has been observed to the north and northeast. In the northeast the dolomite changes in turn, over a short distance, to limestone whose direct continuation apparently is the stromatolitic limestone in boreholes 1803 and 511.

The latitudinal orientation of the richest sideritic zone within the Malaya Shuyda Range and the Shikhansk area, and of the magnesite-carrying dolomite, gives reason to believe that the Gayevskiy quarry is an easterly extension of this sideritic belt. The gradual thinning of the stromatolitic member to the south suggests that here, too, a wedging out of this carbonate member takes place.

The local presence of shale among the carbonate rocks on the southeastern slope of the Malaya Shuyda Range, together with the wide development of stromatoliths, suggests shallow water conditions during the sediment accumulation. Going north, siderite disappears from the section, being replaced first by dolomite, then by limestone; consequently, here, too, the accumulation of siderite is confined to a carbonate deposition province.

The limestone member $Bak_3$. In borehole 1788, 50 meters above the stromatolitic horizon and separated from it by shale and diabase, there lies a limestone member (Fig. 2)[2] represented by dark-gray, almost black, argillaceous varieties, with much carbonaceous material and with a wormy texture. The limestone is broken up by thin shale beds. The middle part of this member carries somewhat lighter-colored pelitomorphous varieties of limestone and dolomite with small asterisk-like inclusions of secondary carbonate. To the south, this limestone is replaced by dolomite split up by shale and containing thick deposits of siderite (boreholes 1762 and 1772). Still farther south, these deposits are obliterated by the pre-Zigal'ga erosion.

In boreholes 1803 and 511, the Irkuskan-Bulandikhin syncline, the same stratigraphic position is occupied by gray to light-gray dolomitic limestone, with a wormy texture and thin intercalations of shale.

Consequently, this member, too, is marked by a southerly change from limestone to dolomite interbedded with shale. The thick siderite deposit in dolomite, too, appears to be located in the transition zone to shale.

The upper carbonate member $Bak_{10}$. Overlying the limestone member, and separated from it by shale, is the upper ore-bearing member having a complex structure.

Its lower part is built up chiefly of fine-grained dolomite, gray to light-gray, bedded, with numerous intercalations of brownish, locally mineralized phyllite-carbonate rocks with a typical wavy-bedded structure. Developed in its middle part are more massive, recrystallized dolomites and dolomitic limestones. The main deposits of semi-oxidized siderite and of brown ore occurs at this interval. The upper part of this member is characterized by the appearance of dolomite and dolomitic limestone with stromatoliths, more or less sideritic, interbedded with calcareous and sandy shale. This ore member has been uncovered by mines Ob"yedinennyy, Voslochnyy, and Bulandikha (Fig. 7), whose disposition reveals a latitudinal trend of the ore belt.

In the southern part of the Ob'yedinennyy mine, brown ores of the same member are associated with shale (Yuzhnaya shaft; borehole 314). To the northeast, the shale gradually changes to carbonate rocks with brown iron ore and siderite (boreholes 306-a and 316; Fig. 8). Farther on, along the northwestern Bulandikha slope, the mineralization is reduced, the siderite beds split up into a number of lenses which grow thinner and gradually wedge out. However, new carbonate beds with siderite appear in the overlying shale. These beds thicken to the north and merge with the underlying carbonate member, to form in the Lenin mine area a single body, up to 100 meters thick, with siderite beds 20 meters thick, less commonly 40 meters.

Northwest of Bulandikha Mountain, in contrast to the general thickening of the carbonate member, siderite wedges out as it does north of the Lenin mine.

On the southeastern slope of the Bulandikha, south of the mine, this member is greatly eroded. Its thickness increases gradually, to the northeast, attaining 45 or 50 meters in boreholes 205 and 206; the total thickness of oxidized ores is about 20 to 25 meters. In borehole 375, this carbonate sequence is as much as 100 meters thick, with siderite no less than 40 meters thick.

From there, the sideritic zone is traceable to the Vostochnoye mine, but north of borehole 375 siderite wedges out gradually (borehole 559).

[2] The absence of the corresponding distribution map for siderite in these deposits is due to the small amount of material, because this member has just been penetrated by drilling.

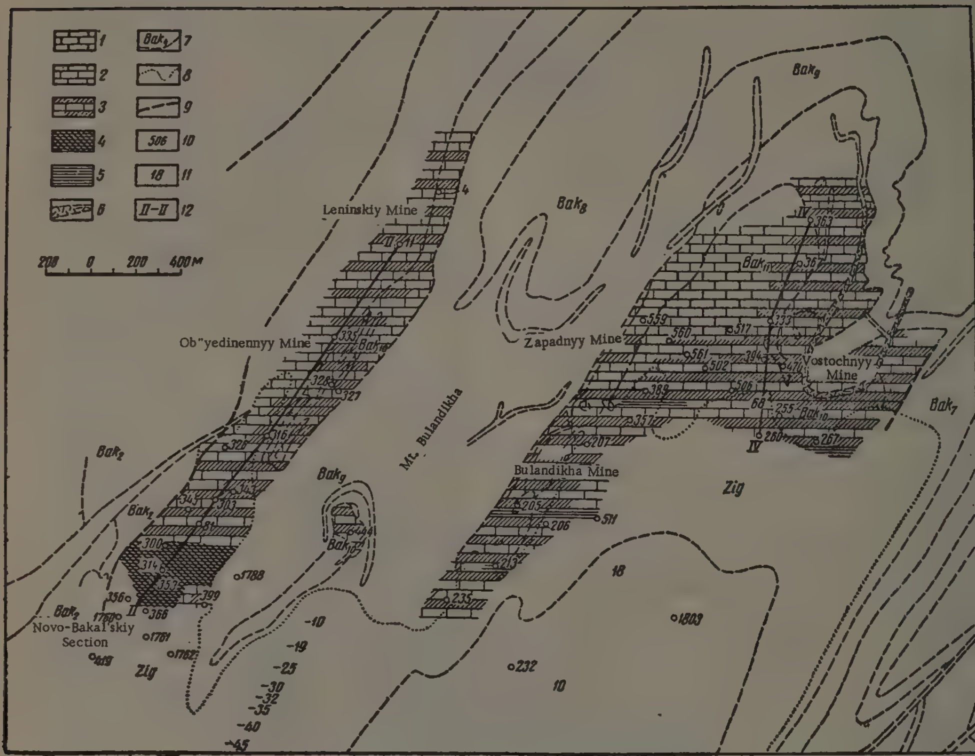


FIGURE 7. Distribution of siderite in member $Bak_{10}$, Bakal' iron ore deposit. Compiled by Z.M. Starostina. Geologic map by Yu.S. Solov'yev, V.A. Knyazev, and Yu.A. Davydenko, under the direction of Professor A.Ye. Malakhov. The map has been refined from the results of work by the Bakal' Geologic Exploration Group, 1950-1957.

1 -- Limestone and dolomitic limestone; 2 -- dolomite; 3 -- dolomite interbedded with siderite or brown iron ore; 4 -- shale with beds of brown ore; 5 -- shale; 6 -- diabase dikes; 7 -- stratigraphic boundary; 8 -- boundary of pre-Zigal'ga erosion; 9 -- faults; 10 -- borehole number; 11 -- cross-section numbers; 12 -- cross-section lines.

Within the Vostochnyy mine (Fig. 7), the ore-bearing rock is as much as 80 meters thick; with a northerly increase in thickness of carbonate rocks, its mineralization falls off gradually (Fig. 9); in the west (boreholes 506, 562, 561) this member is as much as 120 or 130 meters thick, while the overall thickness of siderites does not exceed 30 meters. Still farther north, in borehole 517, the same member is as much as 200 meters thick, with no siderite observed.

The presence of an argillaceous ore-bearing facies along the southwestern foot of Bulandikha Mountain, and the northerly thickening of carbonate rocks in this member — first with a simultaneous growth in the thickness of siderite and then with their wedging out — makes it possible to assume here, too, the association of siderite with the peripheral zone of development of carbonate sediments.

## 2. The Zigal'ga formation

The Zigal'ga quartzite rests, with a deep erosional break, on different members of the Bakal' formation. Present at the base of the Zigal'ga formation are thin lenses of basal conglomerate consisting mostly of quartzite pebbles, a small amount of shale fragments and siderite pebbles bound together by a

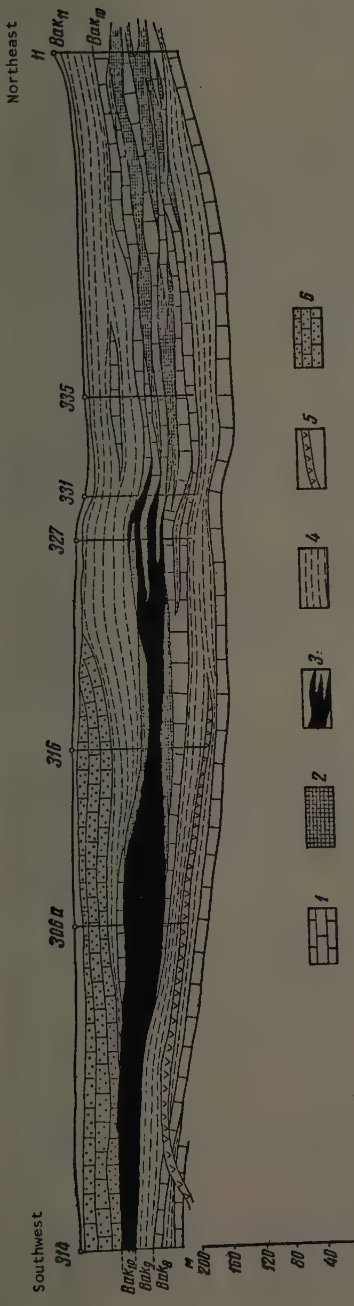


FIGURE 8. Cross section II-II. Compiled by Z.M. Starostina.

1 -- Limestone and dolomite; 2 -- siderite; 3 -- brown iron ore; 4 -- shale; 5 -- diabase; 6 -- quartzite.

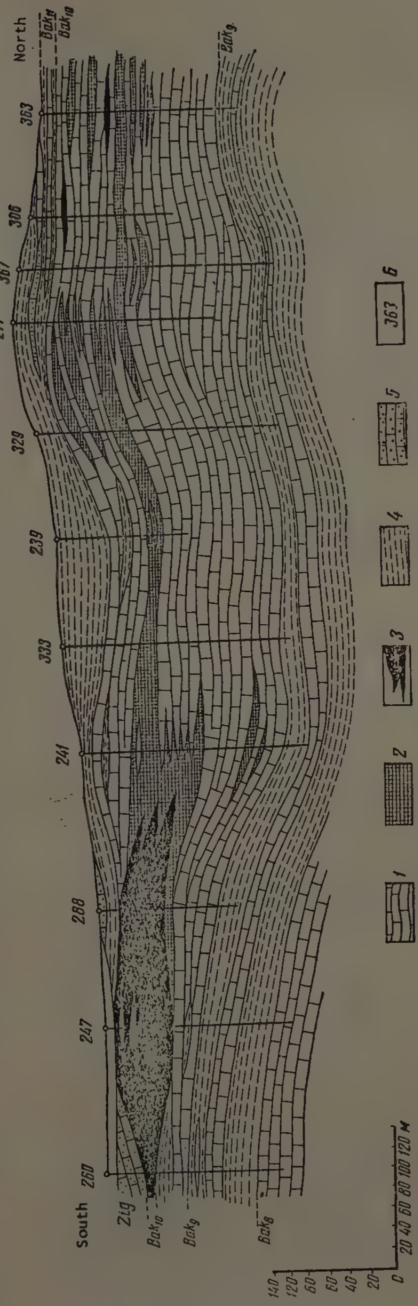


FIGURE 9. Cross section IV-IV. Compiled by N.K. Burgelya.

1 -- Limestone and dolomite; 2 -- siderite; 3 -- brown iron ore; 4 -- shale; 5 -- quartzite; 6 -- borehole numbers.

quartz and areno-argillaceous cement. Above that, there lie white, tough, sugary and then gray bedded quartzite and quartzitic sandstone. Present among them are layers of carbonaceous-argillaceous shale. The total thickness of this formation is estimated at 200 to 250 meters.

### 3. Intrusive rocks

The above-described body of sedimentary rocks is cut by a series of diabase dikes, associated in individual instances with normal faults cutting the folded system; like the faults, they have a northeastern trend, which is evidence of the age of dikes and also the disjunctive dislocations of the region. Most dikes consist of cutting veins, usually trending northeast or else meridionally, and commonly turning into sills. In such cases, their thickness ranges greatly, from 1 to 40 meters.

In their mineralogic composition, they are divided into gabbro diabase, olivine diabase, and diabase porphyry. The contact effect of diabase on the enclosing rocks is usually insignificant.

## III. THE ORIGIN OF THE ORES

At the present time, most geologists hold to the hypothesis of a sedimentary origin of the Bakal' siderite, and there is no doubt that the primary ore consists of ferruginous carbonate. As a result of their alteration, a number of oxidized ores were formed, different from each other depending on the degree of oxidation and on the composition of the primary ferruginous carbonate. The main body of ores is associated with carbonate members. Thin intercalations and lenticular bodies of argillaceous siderite also occurs in shale.

The structure and texture of the ferruginous carbonate and of their richest varieties — siderite — as well as now formations and additions in them — namely carbonaceous matter, silty and psammitic particles — are on the whole the same as in the enclosing dolomite. The main mode of occurrence of primary ferruginous carbonate deposit is bedded, wherein it does not appear to occur as strictly circumscribed ore bodies but rather closely related — by way of gradual transitions — to the enclosing dolomite whose facies they are. The Bakal' siderite contains variable amounts of argillaceous matter and silica.

The boundaries of oxidized ores usually are sharper.

According to L.M. Miropol'skiy [13], the Bakal' sideritic ores are very rich in magnesium carbonate and approach sideroplesite and pistomesite in composition.

D.S. Belyankin and V.V. Lapin [1] have come to the conclusion that rich siderites are compounds of iron carbonate with an addition of carbonates of magnesium, calcium, and manganese in solid solution, i.e., they consist of a single sideritic phase while the lean ones consist of two phases — sideritic and ferruginous dolomitic.

In comparing the thermodiagram data for carbonate ores with the results of thermal analyses of monomineral formations from an ore-bearing complex (calcite, magnesite, secondary dolomite, and ankerite), A.Ye. Malakhov [11] has concluded that "because of the considerable solubility of magnesium in iron carbonate, the Bakal' siderite consists of iron carbonate compounds with isomorphous additions of magnesium and some manganese," corroborating the view of D.S. Belyankin and V.V. Lapin.

The several theories of the origin of the Bakal' siderites are considered in detail by N.A. Ushakov [19] who discusses them in three groups. The first group includes views grouped under the hypothesis of replacement of dolomite and limestone by vadose and ferruginous solutions, with meta-shale and diabase as the primary source of their iron.

Most geologists adhere to the second hypothesis, that of hydrothermal metasomatism (P.A. Zemyatchenskiy, Ya.V. Samoylov, A.N. Zavaritskiy, G.I. Mokshanov, L.M. Miropol'skiy). According to this hypothesis, siderite originated from the replacement of dolomite and limestone by thermal ferruginous solutions of a hypogene origin. The sources of these thermal solutions were igneous intrusions. Such solutions could have been ferruginous from the moment of their separation from the source, while most iron was extracted by thermal currents, from meta-shale.

The third group assumes a sedimentary origin of the primary ore mineral (D.V. Nalivkin, A.D. Arkhangel'skiy).

In criticizing the hypothesis of a hydrothermal-metasomatic origin of the Bakal' siderite, N.A. Ushakov regards as inadequate its explanation of the bedded occurrence of siderite, as well as the presence of ore beds separated by shale and associated with definite stratigraphic units. In addition, that author believes that the hypothetical aspect of the origin of mighty thermal currents is one of the weakest points of this theory; in his opinion, there is no good reason to connect thermal currents of any magnitude with the

Berdyaush diabase or granite. The presence of a number of minerals peculiar to hydrothermal formations and observed only in veinlets and hollows in siderite is, according to N.A. Ushakov, a later phenomenon related to thermal currents accompanying the diabase intrusions.

According to him, dolomitic limestone, dolomite, and siderite could have been formed at the bottom of a Bakal' lagoon as a chemical precipitate or else from dolomitization and sideritization of a calcareous sediment, as an effect resulting from sea water on it. He also believes in diversified sources of iron, ie.e, that there could have been ferruginous or carbonate ferruginous springs on the sea bottom or on the shore; iron could have been brought in by a river and extracted and concentrated by living organisms, often in a ferrous state.

The formation of sediments was followed by an early diagenesis, i.e., by dehydration and crystallization. The formation of a medium- to coarse-grained crystalline structures and of some minerals, as well as the development of veinlets of carbonate, quartz, and pyrite is relegated by N.A. Ushakov to a later stage of diagenesis and metamorphism.

The origin of secondary oxidized ore is relegated by that author to the third stage — that of weathering by the action of water, air, and temperature.

The view favoring a sedimentary origin of the Bakal' siderite is also shared by A.Ye. Malakhov [10-12]. That author supports D.V. Nalivkin's view [15] of the Bakal' siderite ores having been deposited under lagoonal or littoral conditions; he emphasizes, however, that in a long process of subsequent folding, the Bakal' siderite underwent considerable metamorphism.

Yu.A. Davydenko [6, 7], who conducted most of his investigations in the Bulandikha Mountain area, shares the view of A.N. Zavaritskiy [8, 9] and believes that a hydrothermal-metasomatic origin of siderite is incontrovertible. The replacement of siderites from north to south, as observed in the Bulandikha mine in member $b_8^2$, first by dolomite then by limestone, Yu.A. Davydenko explains by the selective character of metasomatic processes, and he regards the boundaries between these lithologic varieties as cross contacts.

Interpreting the occurrence of most Bakal' ore deposits as evidence of a relationship with the surface of the angular unconformity between the Bakal' and the Zigal'ga formations, that author genetically relates both the formation of siderite and the emergence of altered rocks at the erosion boundary with the screening effect of the Zigal'ga quartzite.

In our opinion, the definite position of the Bakal' ore deposits, both vertically and areally, fully confirm their sedimentary origin. This ore deposit occurs in an area where periodic changes in conditions favorable for the accumulation of argillaceous sediments, rich in organic matter occurred. This also was a deposition site for carbonates rich in iron and magnesium, with an addition of fine terrigenous material. In other words, the Bakal' ore deposit is located in a zone transitional from a carbonate facies characteristic of the corresponding interval in the north and northwest of the area — to the terrigenous facies in the south and southeast. The fact that the largest deposits are genetically related to these conditions is evidence of the thick siderite bodies having been formed in a definite facies environment which was determined by the composition of accumulated material, on one hand, and by initial stages of diagenesis in the ooze, on the other.

The formation of dolomitic sediments, rich in iron, without any evidence of their lagoonal origin, and paragenetically connected with limestone and with iron rich terrigenous sequences suggests the presence here of a peculiar marine basin with an influx of waters rich in calcium, iron, and magnesium. The iron could have been brought in by surface waters which eroded the ferruginous quartzite and jaspilite, widely distributed in the Precambrian, in both the platform area and in the geosyncline itself; another source of iron could have been, as pointed out by N.A. Ushakov, ferruginous-carbonate-magnesium springs at the basin bottom.

According to N.M. Strakhov [17, 18], the distribution of iron is determined by two factors: 1) iron, transported by rivers, enters seas and lakes chiefly in mechanical suspension and gravitates toward its finest fraction; 2) iron in solution is chemically precipitated in extremely fine gel clots which the water carries to more distant reaches of a basin. The latter process appears to have been predominant, resulting in intensive enrichment in iron oxides, in a zone immediately beyond that of the terrigenous material deposition. It is here, in the end zone of chemical deposition of carbonates, that the main coagulation and precipitation of iron compound gels took place. At the same time, here, as in the zone of accumulation of terrigenous material, much organic matter was deposited, as witness tne abundance of carbonaceous matter in shale and carbonate rocks. Subsequently, organic matter participated in the diagenetic process of reduction of ferric iron and in the formation of carbonate salts.

Thus the transition zone from terrigenous sediments to chemically precipitated limestone was marked by the accumulation of carbonate salts of Ca, Mg, and Fe. Magnesial dolomite and ferridolomite were formed in the process. These two varieties are miscible in any proportion, which is what takes place in the Bakal' siderite which include compounds of iron carbonate and isomorphous additions of magnesium and some magnangese. It follows that sedimentation processes predominated in the initial stage of formation of the Bakal' ores.

The origin of the main body of siderite ores proper is connected with diagenetic processes which included not only the reduction of ferric compound into the ferrous but also a bringing together of mineral matter diffused in the sediment, in a manner similar to the formation of concretions. The constant presence of inclusions of secondary recrystallized siderite in carbonate ores suggests a later redistribution of matter and a growth of coarser crystalline bodies as a result of epigenetic metamorphism in the process of crystallization.

To the same stage of formation of siderite deposits probably belongs the increase in their thickness, commonly observed in the crest of anticlinal folds. Because the unity of beds was broken in those places, there was a loss of $CO_2$ from the circulation waters and a more intensive precipitation of carbonate salts — especially of iron carbonate, because of its mobility. This was accompanied by the influx of fresh solutions from the adjacent synclinal area.

## IV. SUMMARY

1. Bedded siderite ores of the Bakal' group, changing to brown iron ores in the oxidation zone, are associated with five carbonate members alternating with shale members to form the Riphean Bakal' series.

2. The carbonate ore deposits, being replaced by shale, in the south and southeast, wedge out consecutively, retreating from south to north.

3. As a rule, siderite deposits are associated with dolomite; the latter, replacing limestone, are distributed in the peripheral belt of the carbonate rocks area, near the zone of transition to an argillaceous facies, also ore-bearing in a number of places.

4. The distribution of siderite ores, associated with definite stratigraphic members and, what is more important, with a peculiar facies environment, points to their sedimentary origin.

5. The general strike of the entire ore zone, associated with the carbonate-terrigenous transition of the Bakal' facies, is to the northeast. But the richest sideritic facies are oriented latitudinally, which probably is connected with the tectonic development of the Uralian foredeep where it joins the Ufa plateau.

The enclosed distribution maps of siderite for each member are the first attempt at relating the distribution of ore deposits with the changes in thickness and composition of enclosing rocks. Naturally, these maps do not pretend to be absolutely correct and final, especially as regards the boundary lines between the several lithologic units; but even at that, they may be helpful in prospecting and in planning future exploratory work. For instance, it is now perfectly clear that the transition zone to shales is especially significant for each carbonate horizon. In this connection, the transition zone of carbonate sideritic rocks of the $Bak_2$ member, on the southeastern Malaya Shuyda slope, where it changes to limestone (Berezovsk member) of the Irkuskan Range is especially interesting; also interesting is the behavior of an ore-bearing member of magnesite dolomite, south and southeast of the OGPU mine.

Because of the latitudinal trend of richer sideritic facies, the observed extension of siderite of the magnesite dolomite and of the stromatolitic member, along the strike, within the Irkuskan-Bulandikhin syncline, is of special interest. Significant in this connection are the sections of boreholes 1011 and 1700, in the syncline, which have penetrated the Zigal'ga quartzite and the underlying shale, penetrating an alternation of shale and dolomitic shale, with dolomite and siderite, apparently of the stromatolitic member, underlain by magnesite-carrying dolomite and siderite of the $Bak_4$ member.

Areas to the north of these zones appear to be poor prospects, with only small lenticular deposits anticipated; it is possible that bedded deposits of brown iron ore will be found to the south and southeast, in the area of the argillaceous facies.

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Geological Institute,
Academy of Sciences, U.S.S.R.
Moscow

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# SOME PETROGRAPHIC AND PALEOGEOGRAPHIC FEATURES OF SEDIMENTS IN GEOSYNCLINAL FORMATIONS (AS DEMONSTRATED IN THE CAUCASIAN FOLD PROVINCE)[1]

by

V. A. Grossgeym

This paper describes, on the basis of a vast amount of data, the mineralogic composition, granulometry, and texture of a number of principal formations in the outer zone of the Caucasian geosynclinal province and in foredeeps which fringe it -- the slate, flysch, and the lower and upper molasse. The author explains their differences by the different conditions of their origin.

* * * * *

The study of formations has assumed an ever growing importance, in recent years, in the analysis of geologic problems. However, the petrography of sediments, the components of individual formations, has been barely touched upon; we want to fill in this gap, to a certain extent, in regard to some geosynclinal formations.

A summing up and an analysis of vast material accumulated on the mineralogy of the Mesozoic and Cenozoic of the Northern Caucasus and Cis-Caucasus have enabled us to arrive at some general conclusions on the petrography and paleogeography of certain geosynclinal formations; these conclusions are set forth below.

Our knowledge of formations which followed each other within the Caucasian geosynclinal province, during the Alpine cycle, is uneven; the least known are the slate and the upper molasse; the best known is the flysch; the carbonate rocks are practically unknown.

## THE SLATE FORMATION

In agreement with N. S. Shatskiy [26], V. V. Belousov [2], and V. Ye. Khain [24], we interpret a lithologic formation to be a regular combination of paragenetically interrelated lithofacies originating in a definite physical, geographic, geochemical, and geotectonic environment, changing within a definite range; the main elements of such an environment are the nature and the intensity of dynamic activity (M. V. Klenova) of the sedimentation medium.

According to B. M. Keller [16] and V. Ye. Khain [24], the slate developed in geosynclinal foredeeps, at the first stage of development of geotectonic cycles; this stage was marked by a general progressive subsidence of geosynclinal zones, contemporaneous with the rise of geanticlines separating them.

The so-called north Caucasian slope geosyncline [1, 21] was the outer (the nearest to the platform) downwarp of the Caucasian segment of the Thetys, during Jurassic time, where thick areno-argillaceous and silty deposits were laid down. The most intensive downwarping took place at the site of modern Dagestan, where the combined thickness of the Liassic and Dogger is over 10,000 meters. The distribution of lithofacies and the composition of terrigenous minerals suggests that most of the terrigenous material came to a vast trough from the north, from the direction of the so-called Cis-Caucasian land mass; a smaller portion of sediments came from the then few interior uplifts, fringing the trough in a chain of islands, in the south.

The Cis-Caucasian land (Scythian epi-Hercynian platform) was made up of metamorphic, strongly deformed rocks of the middle and perhaps upper Paleozoic (chiefly

[1]Nekotoryye cherty petrografii i paleogeografii osadkov geosinklinal'nykh formatsiy (na primere Kavkazskoy skladchatoy oblasti).

Carboniferous in age), with an areno-argillaceous (quartzite to meta-shale) composition. Although the mineralogic composition of this source of sediments is not yet adequately known, the data on hand, however scanty, do not contradict this assumption. The existence of a principal source of sediments to the north is suggested much more forcibly by their coarsening (argillaceous sediments to silt, to sandy-silt, and finally to sand in that direction), best determined by I.A. Konyukhov in the eastern part of the area under study [18]; it is also suggested by the result of a study of cross-bedding (data of M. Kh. Bulach [3], and the author).

A study of the orientation of cross-bedding has shown that, in South Dagestan, the overwhelming majority of cross-beds dip in the direction of finer facies (to the east and southeast). The same situation has been observed along Kuban' River (where series of cross beds dip in to the south). Along Baksan (Kestanta River) and Malaya Laba Rivers, most cross beds dip to the south: the beds dip both to the east and to the west. Unfortunately, the texture of Lower and Middle Jurassic sandstone (Figure 1) is far from being well known; still, some conclusions -- albeit approximate -- can be made for this interval, as well. The fact is that the measurements along the Little Laba and the Kestanta are made on the base of the Jurassic series; along the Kuban' they were made on higher beds (Plinsbakh); and in Dagestan, on still younger deposits (Toarcian-Aalenian). It is possible that the least consistent and most variable currents existed during the initial stage of geosynclinal downwarping and that they were stabilized, or at least became somewhat more consistent, later on. It should be noted that the currents whose existence has been recognized, up to now, were flowing mostly across a broad trough.

It appears that the mineralogic features of the sediments (Figure 1) that there is a sharp difference in material that came from the Scythian platform and from the interior uplifts. The uplifts were surrounded by small fringes of the products of erosion, chiefly metamorphic and extrusive rocks. These sediments, sand to silt, at times even pebbles, usually were poorly sorted. Their component minerals are marked by their freshness and idiomorphic outlines, with numerous faceted crystals and even druses. Apparently, many minerals represent new formations,

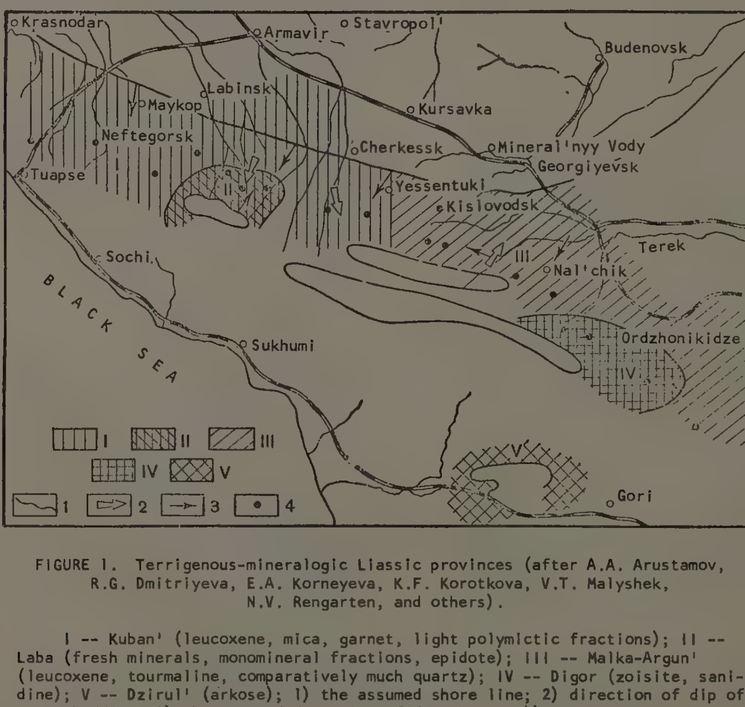


FIGURE 1. Terrigenous-mineralogic Liassic provinces (after A.A. Arustamov, R.G. Dmitriyeva, E.A. Korneyeva, K.F. Korotkova, V.T. Malyshek, N.V. Rengarten, and others).

I -- Kuban' (leucoxene, mica, garnet, light polymictic fractions); II -- Laba (fresh minerals, monomineral fractions, epidote); III -- Malka-Argun' (leucoxene, tourmaline, comparatively much quartz); IV -- Digor (zoisite, sanidine); V -- Dzirul' (arkose); 1) the assumed shore line; 2) direction of dip of cross-bedding; 3) the assumed direction of deposition; 4) sections studied.

although on the whole they have a relict aspect. One of the typical features of heavy fractions is the lack of variety in their components; they are made up almost exclusively of epidote or mica, or of some other minerals. All this suggests a proximity of the source and that these sediments are in their initial phase as clastic material. The light fractions are polymictic, at times arkosic.

Conversely, the bulk of material coming from the platform is marked by a great uniformity and a "worn-out" aspect and by a polymictic aspect of both light and heavy fractions. The abundance (up to 70 percent and more) of the so-called non-ore, opaque minerals most of which are the products of disintegration of other minerals (epidote, ilmenite, etc.) is typical of the heavy fractions. The other minerals, although not rounded as a rule, carry clear evidence of weathering, such as a network of fine fissures, blooms of weathering products, and other features. The same is typical of the light fractions, as well, where many grains are of decomposed minerals, with feldspars also mostly pelitized, sericitized, and kaolinized.

We believe these features resulted from the fact that a very long period (Permian and Triassic) expired from the end of Carboniferous sedimentation to the Cis-Caucasian folding and the onset of the Alpine sedimentary cycle in a foredeep of the Caucasian geosyncline. During that period, the present Cis-Caucasus was a land mass, probably not subjected to intense erosion till the beginning of the Jurassic; for this reason, it developed a weathered crust. Under subaerial conditions, sedimentary rocks were acted upon by atmospheric processes which considerably modified their mineralogic composition. The least stable mineral species were chemically decomposed in a humid or warm climate [22]. The poor rounding of mineral grains was inherited from the Carboniferous sediments, of a clearly geosynclinal nature, and was preserved in Jurassic sediments because of their rapid burial, a result of the intensive downwarping. We believe that this also was the reason for what we assume to be the transverse currents which transported the product of the land disintegration to the basin deeps.

## THE FLYSCH FORMATION

The flysch formation (of N.B. Vassoyevich) corresponds to the second stage of the geosynclinal development, marked by subsidence and by a further extension of marine transgression. Continuing at the same time was the differentiation of geosynclines and geanticlines, formed as early as the first stage, into troughs and uplifts of the second order; this process was initiated as early as the end of the first stage [24]. The most notable formation of the second stage is the flysch which is usually deposited in the second or the third trough, counting from the edge of a geosynclinal province.

The best known in this respect are the Carboniferous flysch basins of southeastern and northwestern Caucasus, also the Paleocene flysch of the western Kuban' region.

Most often, flysch basins present troughs elongated in one direction (the general Caucasian trend, in the present case), long and narrow, bordering on zones of uplift which are expressed geomorphically on one or on both sides in a chain of islands (cordillera). These uplifts may be represented by submarine swells which serve as the boundaries of facies zones.

The Turonian flysch basin of the southeastern Caucasus, which is known in great detail [5, 7, 9, 12, 19, 23], was bounded in the north by a chain of rocky islands, made up of Malm limestone underlain by Dogger shale. In the south, the flysch trough was bounded by a submarine barrier, south of which normal sediments were deposited (red Margalitis-Klde limestone). Islands of the northern cordillera were fringed by conglomerate (Khizinsk) which reflect perfectly the composition of the source rocks (black shale with Posidonia, and light-colored Malm limestone). The conglomerate fringe was no less than 15 kilometers. wide.

Carbonate flysch (Kemch formation) was deposited in the south. It is represented by a rhythmic alternation of gravel (I-a supplement of the rhythm), calcareous silt and silty pelite (I-b supplement), limestone and marly limestone (II-a sub-element), marl and marly shale (II-b sub-element) and noncarbonate shale (element III).

The gravels have a very limited area of distribution. They consist of Malm limestone grains and some reworked fragments of Kemch marl and limestone. The number and the thickness of gravel beds increase to the north, along with grain size. All this suggests that at the time of deposition of sub-element I-a, there was intensive erosion of the northern islands and partial erosion of the underlying rocks, of preceding sedimentary cycles. This is also confirmed by the orientation of hieroglyphs at the base of the cycles [10]. The orientation of hieroglyphs is an index of the environment's dynamics at the iniation of a cycle.

Very interesting observations on the nature of these hieroglyphs have been made in the southwestern Caucasus. The least definite

orientation of the hieroglyph tonuges has been observed in the central part of the flysch trough, where they are scarce and considerably flattened. On the other hand, hieroglyphs in the zone near the cordillera have a clean-cut low and or even high relief, with their tongues clearly oriented to the cordillera. The higher components of the first element of the cycle (I-b sub-element) are made up of calcareous sandstone with alternating cross- and even-bedded structures. The cross beds are definitely oriented parallel to the trend of the flysch trough, thus suggesting longitudinal currents. It is of interest that the least definite orientation of cross beds occurs in the central part of the trough, while the most definite one is associated with the northerly belt, nearer to the cordillera.

In our detailed study of the Turonian flysch area of development in southeastern Caucasus, we have succeeded in recognizing a correlative cycle, in nine out of several tens of sections investigated. The results of petrographic study of sub-element I-a of the cycle are described in a special paper [12]. We mention here only the main results of that work.

It has been determined that the amount of clay and fragments of quartz, rocks and ore minerals, and garnet increases toward the middle of the flysch trough. On the other hand, the amount of feldspar, tourmaline, titanium minerals, octahedrite, sphene, and barite decreases in the same direction. South of the northern cordillera, the volume of the sandy fraction decreases, along with the percentage of the heavy fraction, the average diameter of grains, and the amount of staurolite and carbonates (in absolute figures). Conversely, the amount of rutile increases in the same direction. It should also be noted that a greater variety of accessory minerals is present in sections nearer the northern cordillera.

Terrigenous material in the unit under study has come to the flysch trough from the northern cordillera. This is well demonstrated by the northerly increase in the sandy fraction, in the average diameter of grains, and in the amount and diversity of accessory minerals. The poor rounding of quartz and of other stable mineral grains suggests that there is no need to look for any supplementary source, beyond internal regions.

While the southerly reduction in the coarseness of grain and in the amount and diversity of heavy minerals depends on the increase in distance from the source, the increase or decrease in the amount of most minerals, clay, the percent of carbonates -- symmetrical with relation to the trough axis -- duplicates the distribution of thicknesses and fully corresponds to the form of the flysch trough. It is to be remembered that series of cross beds in sub-element I-b are oriented along the trough; consequently, the currents which carried terrigenous material also moved along it. It is the action of currents that explains the distribution of minerals in accordance with the form of the flysch trough.

Another well-known flysch basin is the upper Senonian Novorossiysk trough. Its paleogeographic conditions were somewhat different [13, 14, 15].

The northern boundary of this flysch trough was represented by a chain of islands made up of Upper Jurassic rocks, and of Lower Cretaceous rocks in the northern facies. The southern boundary of the trough is considerably less known; a fixed facial boundary with normal sediments of a trough (Abkhaz) farther to the south has been recognized only in the Akhtsu Range area. The remaining segment of that boundary zone is in the Black Sea. It appears that a chain of islands was also present in the south [15]. This is suggested by the increase in the amount of sand in sections both north and south of the middle of the trough. It should be noted that the central part of the trough is filled with sediments which may not be called "flysch", but rather "sub-flysch," in the nomenclature of N.B. Vassoyevich. Element II of the cycle is extremely well developed, here, while elements I and III are quite subordinate. Thus, the least amount of terrigenous material is present in the middle part of the trough. B.M. Keller relates such a distribution of terrigenous material to the considerable width of the flysch basin (up to 60 kilometers), exceeding that of other known flysch troughs [15]. This appears to be the most plausible explanation of the facts observed; it is confirmed also by other data.

A study of the mineralogic composition of sediments [13, 14] has shown that the initial elements of bedded flysch sequences carry a fairly monotonous association of minerals, which persists over considerable distances along the strike and undergoes certain changes across it.

The northernmost flysch zone is marked by the presence of magnetite, ilmenite, pyrite, limonite, zircon, garnet, tourmaline, rutile, octahedrite, brookite, sphene, staurolite, disthene (in very small amounts, chiefly in the eastern sections), occasional carbonates, apatite, micas, sillimanite, andalusite, dallite, collophanite, and fragments of carbonate rocks and glauconite in the east. The light fractions contain quartz, feldspars, glauconite, fragments of cherty and carbonate rocks, and muscovite.

The southern sub-province is marked by a somewhat fresher aspect of minerals, by the lack of some minerals peculiar to the northern sub-province, and by different quantitative ratios. The main differences are as follows:

Black ore minerals are more scarce; pyrite is more common; and stable minerals (up to 55 percent) are most typical for the southern belt. They usually are better rounded and less diversified. In addition, the heavy fractions occasionally contain small amounts of apatite, brookite, disthene, staurolite, glauconite, leucoxene, and phosphates. The light fractions consist of quartz (better rounded than in northern sections), fragments of carbonate rocks, feldspar, siliceous aggregates, and glauconite.

The mineralogic composition of sandy-silt rocks in the upper Senonian carbonate zone, north of the flysch trough, is marked by a large amount of disthene and staurolite, and is undoubtedly connected with another terrigenous mineralogic province.

Observations on the orientation of hieroglyphic tongues have shown that at the beginning of the formation of flysch cycles the currents flowed in the general Caucasian direction, along the flysch trough (Figure 2). On the other hand, the orientation of cross beds is less definite, especially in the northern part of the trough (Figure 3). It appears that the currents subsequently lost their consistency and frequently changed both their direction and their intensity to a certain extent. This resulted in terrigenous material being spread over the width of the flysch basin, with some of it reaching as far as its central part.

These conditions determine the monotonous mineralogic composition along the strike of deposition, and its change across it. The composition of light fractions in sandy-silt rocks in which fragments of carbonate rocks as well as quartz play an important part, suggests most likely that some material was derived from older sedimentary rocks. The enrichment of heavy fractions in most stable minerals, together with the near absence of readily broken up components, and with the comparatively high degree of grain rounding, likewise suggests multiple redeposition. Judging from the distribution of terrigenous material throughout the basin (minimum in the middle of the trough; the maximum in peripheral zones), and from their textural and mineralogic features, their sources appear to have been the island chains at the boundary of basins -- the flysch and the one to the north, at the northern slope zone [15].

Some of the minerals came to the basin only from the northern island chain (the serrate staurolite, pink and yellow garnet, red-brown rutile, sphene, etc.), causing the peculiar aspect of the northern terrigenous mineralogic sub-province of the flysch basin.

The paucity of mineral species in contrast to the predominance of stable minerals is

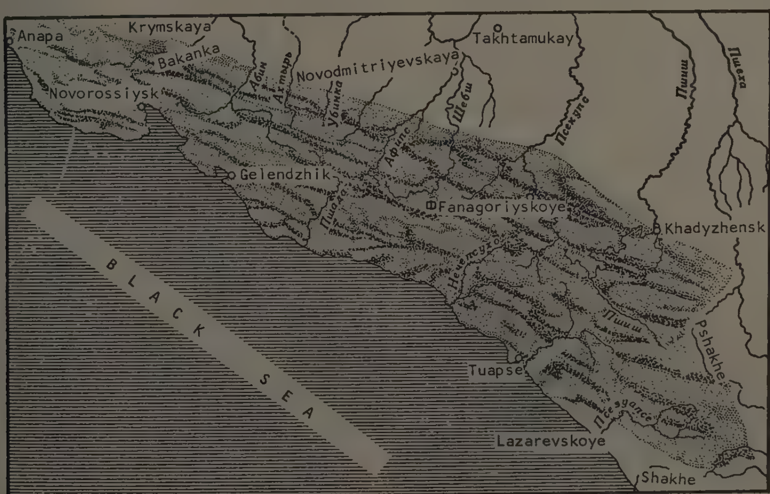


FIGURE 2. Orientation of hieroglyphic tongues in the upper Senonian flysch basin, northwestern Caucasus.

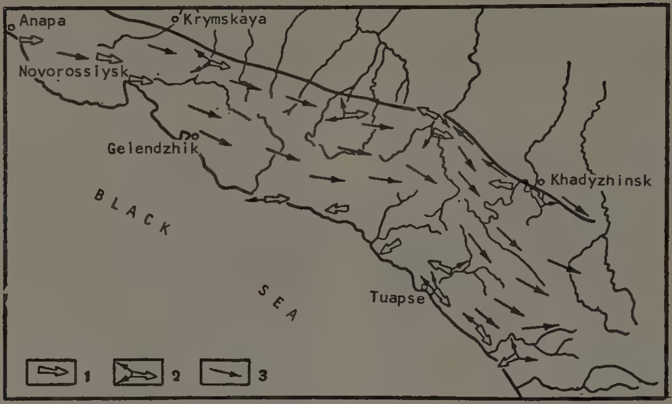


FIGURE 3. Diagram of currents in the upper Senonian flysch basin of the Caucasus.

1) main direction of dip of cross-bedding; 2) secondary directions; 3) assumed directions of principal bottom currents.

typical of the southern sub-province. Their source was located to the south and southeast of the flysch trough; however, some northern minerals, such as disthene, did drfft in here. Finally, another basin was located north of the island chain, where carbonate sediments of a normal type were deposited. Here, sandy-silt rocks are very rare among the limestone and marl, being developed in the southern part of the basin.

The abundance of disthene and staurolite is typical of the sandy-silt rocks. In so far as much terrigenous material is not likely to have come from the north, the extent of the erosion of a cordillera separating the flysch and this basin could have been important in the formation of sediments. The difference in the amount of terrigenous material dispatched to the north and the south from this island chain may be explained by the islands' relief and by differences in the geotectonic conditions of the two troughs.

These two examples are sufficient for a conclusion on the nature of sedimentation in flysch basins. First, it should be noted that the supply of terrigenous material for flysch basins came exclusively from interior uplifts, most often archipelaga-cordillera, separating a flysch basin from adjacent basins, of a different type. Some terrigenous material came to such basins from more distant land masses, located along the trend of the trough but outside of it. Those uplifts, however, were also interior, although formerly consolidated into large land areas. Thus, the foremost characteristic of flysch sedimentation is a supply of terrigenous material derived exclusively from interior uplifts of a geosynclinal province long before the development of flysch troughs. Sediments enriched in northern material subsequently entered the islands bounding the flysch basins in the north.

The second characteristic feature of the flysch basin deposition is the distribution of minerals; along such troughs, the mineralogic associations change very gradually; across them, they change rapidly over short distances. This fact, as we have pointed out before, is related to the action of currents which spread terrigenous material along a trough. At the onset of a new cycle the currents were definite, flowing either along or across a flysch trough, depending on the nature of downwarping which determined their compensatory mechanism. The coarsest and least sorted sediments were deposited at that time. Later on, the currents were oriented chiefly along a trough, although still fairly inconsistent, both in space and time [7, 13]. The comparatively well-sorted siltstone of sub-element I-b was formed as a result. Finally, the currents were slowed down even more, and only a pelitic type of terrigenous material reached the basin (elements II and III of the cycle).

We see, then, that the relationship between present mineralogic associations and bottom currents is most clearly expressed in sediments of the flysch formation.

## LOWER MOLASSE FORMATION

The molasse formation, on the whole, was subdivided almost simultaneously, although independently, by N. B. Vassoyevich [6] and V. Ye. Khain [24], into two separate groups, the lower molasse and the upper molasse. The lower molasse corresponds to the third stage of development of geosynclinal zones, characterized by the dominance of uplifts over subsidences.

Among the typical lower molasse formations in northern Caucasus and Cis-Caucasus are Oligocene, Middle, Lower and some Upper Miocene sediments.

During the Oligocene the final formation of a system of foredeeps fringing the rapidly rising mega-anticline of the Greater Caucasus occurred in the north. The greatest relative height (in the Oligocene and Lower Miocene) was attained in the Greater Caucasus apparently in the Middle and Upper Oligocene. This was the period that witnessed, almost everywhere, the deposition of sandy-silt sediments and conglomerate, often of block size fragments, and of a landslide origin. The presence of landslides was recognized for northern Dagestan and the Chernyye Mountains [25] and in the northwestern Caucasus [4]. They are striking evidence of rapid uplifts accompanied by an intensive abrasion of the young land by immense submarine slides. These events are everywhere associated with the first half of the Middle Oligocene. This was followed by the formation of foredeeps, compensated by sedimentation. As early as the Middle and Upper Oligocene, the distribution of lithofacies was marked by a development of sandy-silt formations in a belt adjoining the Caucasian land mass, on one side, and the platform on the other. During the Oligocene and Lower Miocene, these two bodies were separated by a wide belt of argillaceous formations. The deepest parts of the foredeep were located comparatively near the Caucasian land mass.

The northern sand and silt are definitely of a platform origin (they include residual quartz, disthene, staurolite, sillimanite, zoisite, ilmenite), with the material coming to the basin from interior parts of the platform. The southern material is unquestionably of Caucasian origin. The source province, because of a deep erosional cut, had been abundantly enriched by Jurassic arenoargillaceous rocks. The amazing similarity in the mineralogic composition of the Jurassic and the Maykop should be emphasized (the abundance of chloritoids, apatite, and so forth). Both the siltstone and mudstone of the Maykop Cis-Caucasian silty-clay lithofacies have practically the same monotonous mineralogic composition (with corrections for the granulometric type of sediments). As to the clay zone, the very poor mineralogic composition of its silty fractions precludes an exact determination of the source of clays. Chances are that material came to this part of the basin from both the north and the south.

A comparison of the paleogeographic conditions prevailing in the Middle and Upper Oligocene and Lower Miocene brings up the startling fact that the number of terrigenous mineralogic provinces recognized in sediments fringing the Caucasian land mass decreases considerably with the thinning of sediments. The intensity of erosion was lowered, and chiefly argillaceous material was brought into the basin from the Caucasian side. At the same time, the Cis-Caucasian basin became constricted in the Lower Miocene, so that the platform material reached more southerly points (e. g., Dagestan). The basin was the narrowest in the Middle Miocene, and the platform quartz sands were deposited as far as the middle part of the foredeep and even at its south edge. A peculiar situation was created when sandy material was brought in from the north, and the argillaceous material from the south. The mineralogic aspect of the sands and clays is quite different. A probable cause of that was the cyclic nature of the oscillatory movements, which determined the periodically greater intensity of erosion -- first on the platform, then on the Caucasian land. The mixing of material is perceivable to a small extent at the southern limb of the trough (Chernyye mountains) where quartz sand with disthene and staurolite have an addition of andesine, epidote, and other Caucasian minerals.

The same situation prevails in the Azov-Kuban' trough, in the Meotian (V. T. Malyshek). Sand and siltstone (with quartz, disthene, staurolite, sillimanite) alternate with clays (with stable and titanium minerals) of a different mineralogic composition. In more southerly sections, in the belt of Meotian outcrops, the mineralogic composition of clay, siltstone, and sand is the same (stable and titanium minerals).

Thus, foredeeps of the lower molasse stage are marked by an alternation of sediments of a different lithologic and mineralogic composition, brought in periodically -- first chiefly from the platform, then from geosynclinal provinces. We believe that this may be explained by the lack of correspondence -- or rather by a peculiar linkage -- between positive movements on the platform and in the geosynclinal province. (Other explanations may be possible). An acceleration in positive movements on the platform was scrutinized with their lag in the geosynclinal province, and vice versa. Both movements were

compensated by downwarping in foredeeps, which, too, could have proceeded at a different rate. This is suggested first by the very fact of differentiation of the foredeep sediments into individual beds of different lithologic composition; second, by the presence not only of sand, siltstone and clays but also of carbonate sediments (marl, dolomitic marl, measured usually in centimeters and decimeters). The latter were formed chiefly during periods when a minimum of terrigenous material reached the basin, i. e., during periods of relative quiescence of the platform-foredeep-geosynclinal province system.

The currents instrumental in the spreading of terrigenous material are better known from the eastern part of foredeeps in the area under study [8, 11].

In the Middle and Upper Oligocene and Lower Miocene, the currents prevailing over the present eastern Cis-Caucasus flowed, on the whole, from west to east, coincident with the foredeep trend. Their character changed but slightly, in time, as is clear from a comparison of maps of the Middle and Upper Oligocene and Lower Miocene.

Thus, for a long period of time, the currents were very consistent in general and at each given point. However, the direction and the intensity of currents changed radically in the Middle Miocene [8]. The main current flowed from north to south; reaching the site of Peredovyye Front Ranges, it split into two branches. One proceeded southwest (Peredovyye Ranges, Chernyye Mountains); the other, to the southeast (Dagestan). The two branches coincided more or less with the foredeep trend, except for a slight slant. It is of interest that the character of cross bedding changes from the northern sections to the southern. Inconsistencies have been noted in the southernmost sections, expressed in the suggested northerly directions. It also should be noted that, although the overall direction of Middle Miocene currents was consistent, they did change in time, at individual points, at times to a considerable extent. A map for the entire Middle Miocene does not give the same clear picture as that for the Chokrak and Karagansk basins, individually; the direction of currents is best delineated on maps drawn for individual sand members ($\Sigma_7$ in the Chokrak; $S_6$ in the Karagansk; [8].

Another example of sedimentation in the environment of bottom currents is a belt in Middle and Upper Oligocene sand and siltstone, traced by hundreds of boreholes in the northwestern Caucasus. Sandy formations in an Oligocene-Lower Miocene clay series are exposed in the Neftegorsk area. They have been traced in boreholes across a belt about 12 kilometers wide and trending west-northwest for about 150 kilometers to Severskaya station. Clay was deposited near the coastline (in a belt about 5 kilometers wide), with conglomerate, sandstone, and siltstone deposited immediately offshore (Figure 4). The dip of cross bedding in the Neftegorsk area coincides with the trend of a sand belt to the northwest. The amount of sand in the section, and the grain size in visibly granular rocks, decreases west-northwest, away from the outcrops. The dip of cross bedding is also oriented to the northwest. All this suggests that sedimentation proceeded under a fairly powerful current running parallel to the coast, but some distance away from it.

We already have mentioned that the bottom


FIGURE 4. Belt of sands deposited by bottom currents. Middle and Upper Oligocene, western Kuban' region.

1) Clay; 2) clay with rare intercalations of sand; 3) clay with thick sand beds; 4) conglomerate, sand, clay; 5) the assumed shore line; 6) direction of dip of cross-bedding; 7) direction of currents; 8) sections studied.

current maps (showing orientation of cross bedding), drawn for the shortest possible time intervals, differ from those drawn for entire groups and stages. The same is true for maps of the terrigenous mineralogic provinces. L. P. Gmid [9] prepared such maps for individual stages of basin development. A study of these maps reveals that the detailed distribution of terrigenous minerals changes to a considerable extent, even for comparatively short time intervals. If we recall that in the Oligocene and Lower Miocene, when the currents were considerably more consistent, the mineral associations too, were consistent, the relationship between the distribution of terrigenous minerals and bottom currents will become sufficiently clear.

## THE UPPER MOLASSE FORMATION

This formation corresponds to the fourth stage of development of a geotectonic cycle described by V. Ye. Khain as an abrupt intensification in the growth of the front and the interior uplifts, now transformed into major mountain ranges, and a subsidence of intermontane troughs and foredeeps.

This stage is fully correlative with the Pliocene of the Caucasian geosynclinal province, although in the central parts of Cis-Caucasia the upper molasse was initiated in the Upper Sarmatian.

Pliocene gravel beds fill the major intermontane troughs (Kura depression) and foredeeps to a considerable extent. Many of these troughs have since been closed, with their sediments folded and expressed geomorphically in ranges (Peredovyye, Adzhinour, Yuzhnaya Kakhetiya and other ranges). In the central part of the northern slope, Upper Miocene-Pliocene pebble beds rest monoclinally, forming a comparatively low ridge traceable over a considerable distance. Their stratigraphy is not adequately known, as yet. Better differentiated are the areno-argillaceous sequences which replace the conglomerate, going north, west, and east. These beds are also better known petrographically.

The petrographic composition of the gravel

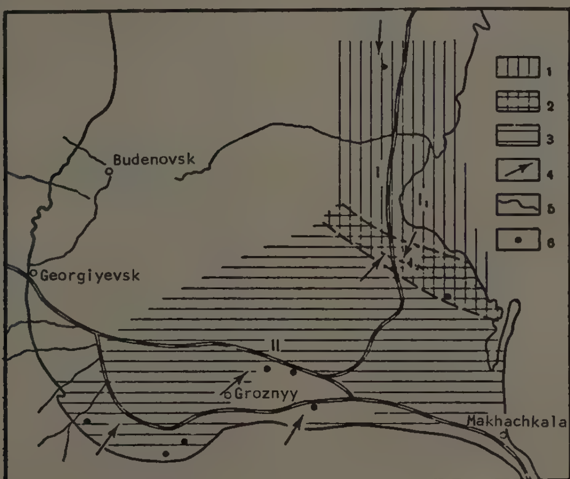


FIGURE 5. Terrigenous mineralogic provinces of the Apsheronian (after S.A. Blagonravov, N.P. Kolpikov, V.S. Safonova, K.I. Smol'yaninova, and others).

1) Northern, Artesian sub-province (much quartz, disthene, staurolite, sillimanite, epidote; scarcity of pyroxenes and amphiboles); 2) Northern Aleksandrian sub-province (less quartz, disthene, staurolite, sillimanite, epidote; more pyroxenes and amphiboles); 3) Near-Caspian (pyroxenes and amphiboles predominate; stable and titanium minerals scarcer); 4) direction of sedimentation for terrigenous and volcanic material); 5) assumed shore line; 6) sections studied.

beds is far from being fully known. We only know that it reflects fairly well the geologic environment of the present Greater Caucasus, but the time relationships are still obscure. In any event, the important thing is that there is no doubt of the Caucasian origin of this gravel material.

As regards the areno-argillaceous sequences contemporaneous with the gravel beds, northern material coming from the platform usually was concentrated far away from the southern shores of basins, with the exception of the productive Apsheron interval (Fig. 5).

It appears, then, that material coming from the Greater Caucasus interior uplift was of great importance. Some distance away from the south shores of basins, the northern platform material appeared first as an addition to the Caucasian; still farther north (Zaterechnaya Plain), it was replaced by Caucasian material. Only in the Middle Pliocene, when the eastern Caspian trough was constricted as never before, did northern material reach the latitude of the Apsheron Peninsula. Although the nature of currents in upper molasse basins is very little known, as yet, it may be assumed that in the Dagestan sector of the Akchagyl'sk basin, with the greater irregularity of its currents, northerly currents prevailed, flowing along the coast. The Chernyye Mountains area currents [20] flowed in the same direction. In the Kimmerigian of the northwestern Caucasus, the currents flowed from south to north (as recorded at a very few points). Only on the Apsheron Peninsula did the Middle Pliocene currents flow from north to south [17].

Thus the prevailing currents flowed across the basin, chiefly from the direction of a Caucasian land mass.

It is important to note that upper molasse sediments are marked by poor sorting and a comparatively good rounding of most material, by the diversity of mineral species, and by common and considerable addition of volcanic components (especially in the Upper Pliocene).

## SUMMARY

Summarizing briefly, the slate formation had a source of terrigenous material in the direction of a platform land mass; interior uplifts played a very small part in sedimentation. The flysch basins were fed exclusively from interior uplifts. During the formation of the lower molasse, material came to foredeeps first from the platform, then from the ever growing interior uplifts. Finally, the upper molasse is marked by the great amount of coarse terrigenous material which arrived from the rapidly rising Greater Caucasus mountain system (an "interior uplift").

The currents usually flowed either longitudinally or transverse to the troughs. During the time of deposition of the slate, the currents were chiefly transverse, from the platform to the trough. In flysch basins, transverse currents originated at times during the deposition of the initial elements of a cycle; the rest of the time, they were longitudinal. The lower molasse basins were marked by a complex system of currents, with the longitudinal (along the troughs) predominating. Finally, the deposition of the upper molasse was marked by prevailing currents from the interior Greater Caucasus uplift to the deeper parts of the basins.

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Krasnodar Affiliate,
All-Union Petroleum,
Scientific Research Institute.

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# STRATIGRAPHY AND GEOLOGIC HISTORY OF THE EARLY CAMBRIAN IN THE NORTHERN PART OF THE YENISEY RANGE[1]

by

M.A. Semikhatov

Lower Cambrian stratigraphy of the northern part of the Yenisey range is among the least known of the geologic problems of that region; there is virtually nothing, as yet, on its geologic history in the literature.

First information on the geology of this region was published at the end of the XIX century by L.A. Yachevskiy. In 1924-1930, I.G. Nikolayev offered a classification of formations in that area [8, 9], which was reworked by A.N. Churakov [13]; in 1938-1941, T.M. Dembo and G.I. Kirichenko essentially duplicated its Cambrian section. Many new data on the geology of the northern Yenisey Range were obtained in 1949-1950 by the Evenkiysk All-Union Aero-Geological Trust expedition (O.P. Goryainova, G.F. Lungersgauzen, R.I. Miloserdova, N.E. Shul'ts, Ya.D. Shenkman, E.A. Fal'kova, and others). These geologists carried out the first geologic survey of the area and worked out a stratigraphic classification for the Precambrian and Cambrian, which has become a basis of all subsequent investigations. Working here in recent years were O.A. Gliko [1], V.N. Grigor'yev [2], G.I. Kirichenko [6], F.P. and Ye.K. Kovrigin, Ye.V. Pokrovskiy, G.S. Nesmikh, and others.

The author of this paper, in 1957-1958, crossed the area of development of the upper Proterozoic and Cambrian, along the Teya, Chapa, Vorogovka,[2] Bol'shaya Chernaya, Bol'shaya, Pravaya Lebyazh'ya, and Isakovka Rivers (Fig. 1). New data on Lower Cambrian stratigraphy are given below.

## THE LOWER CAMBRIAN STRATIGRAPHY

In the area under study, the Cambrian rests upon lower Proterozoic crystalline schists, gneisses, and marbles (the Karpinskiy Range and Pengenginsk formations); upper Proterozoic meta-shales, quartzites, limestones, and dolomites (Udereysk, Pogoryuysk, Kartochki, and Chernorechensk formations); and Precambrian granites [1, 6]. The Precambrian is exposed in the crest of the Karpinskiy Range anticlinorium and in the nuclei of uplifts which complicate the structure of two adjoining synclinoria, which are filled with Cambrian rocks.

The Lower Cambrian of this area is differentiated into the Lopatinsk, Chivida formations, and its correlative Vorogovka, Nemchana, and Lebyazh'ya formations. The first four are associated with the Aldan stage, whereas the Lebyazh'ya formation belongs to the Lower Cambrian Lena stage.

The Lopatinsk formation is of small distribution. Its best section is exposed along the Teya, at the mouth of the Lopatinskiy Creek. Its base, unconformable on the Udereysk shales, is represented by a three-meter thick conglomerate layer, brown-red, of poorly rounded pebbles, 1 to 8 centimeters; gray Udereysk shales (drab colored on the surface); and some quartzites and quartz. These conglomerates lie at the base of a 400 to 450 meter thick sequence of cherry-red fine-grained sandstones and siltstones. Similar rocks rest unconformably on the Precambrian in the upper courses of the Talaya and Koloma Rivers (T.M. Dembo, A.Kh. Ivanov), and along the Teya River, at the mouth of the Yukhtalik Creek. This formation is missing in other places of our area.

The Chivida formation is widely distributed northeast of the Karpinskiy Range anticlinorium, and is represented by a varied thickness of terrigenous rocks and subordinate dolomites.

Along the Teya River, at lake Talyy, the Udereysk formation is overlain unconformably

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[1] Stratigrafiya i geologicheskaya istoriya nizhnego kembriya severnoy chasti yeniseyskogo kryazha.

[2] The route along the Vorogovka was made in the company of V.N. Grigor'yev. Actively participating in the 1957 work was Ye.A. Yelkin, a senior in Moscow State University. I take this opportunity to express my deep gratitude to these two men who shared with me the joys and the hardships of life in the field.


FIGURE 1. Index map of the northern part of the Yenisey Range.

Dotted area is the Lower Cambrian outcrops. Designated with numerals are the following localities: 1 -- Lake Talyy; 2 -- Pod''yem Creek; 3 -- Noyba River; 4 -- Tayezhnyy Creek; 5 -- Nemchana River; 6 -- Chivida; 7 -- Chingasan River; 8 -- Suktal'ma River; 9 -- Bol'shoy Almanakan River; 10 -- Kamenistaya River; 11 -- Pravaya Lebyazh'ya River; 12 -- Bol'shaya Kolonka River; 13 -- Malaya Severnaya River; 14 -- Mokraya River; 15 -- Malaya River Levoberezhnaya; 16 -- Dubches River.

by the following rocks (reading upward:

1. Conglomerates, cherry-red, with semi-rounded pebbles, 0.5 to 8 centimeters, of the Udereysk schists and, in places, by quartzites, quartz, and pink dolomites; thickness 3 m;

2. Dolomites, cherry colored in lower 25 meters, interbedded with sandstones; higher up, light gray dolomites, interbedded with argillites; 55 meters.

3. Argillites, gray, with numerous thin (0.5 to 1 centimeter) lenses of gray fine-grained sandstone, separated into members 1 to 3 meters thick, by 15 to 30 meter thick layers of similar sandstones; 90 meters.

4. A rhythmic alternation of beds, 1 to 2 meters thick, of gray fine-grained sandstones and of units, 0.5 to 2 meters thick (as much as 10 meters, toward the top), of a rapid alternation of gray argillites and sandstones; 85 m.

The total thickness of the Chivida series is 230 meters. Red sands of the Nemchana series lie above it.

South along the river, at the village of Teya, the structure of the Chivida formation is somewhat different. Without any visible unconformity (the contact is not exposed), the

Lopatinsk formation is overlain here by the following rocks (reading upward):

1. Gray dolomites, thin-bedded, fine-grained, with small lenses of black chert; about 100 meters.

2. Light gray sandstones, fine grained to coarse grained at the base; higher up, they are broken by lentils of gray argillites into layers 1 to 5 centimeters thick; 100 meters.

3. Gray argillites with numerous layers and lenses, 0.5 to 2 centimeters and thicker (0.5 to 1.2 meters), of sandstones similar to those below, with intervals of 2 to 5 meters between them; 300 meters.

4. A regular alternation of thick (2 to 4 meters and as much as 7 meters) beds of greenish-gray, fine-grained, calcareous polymictic sandstones and of units, 3 to 10 meters thick (in places as much as 30 m), of a rapid (every 20 to 40 centimeters) rhythmic alternation of greenish-gray, calcareous, silty sandstones and less commonly of argillites. This member, typical of the Chivida formation, is very similar to flysch [3] in its build-up; its thickness is 400 to 450 meters.

The total thickness of the Chivida formation is 900 to 950 meters.

South of the village of Teya, the Chivida formation truncates the Lopatinsk formation and passes over to the Lower Proterozoic and granites. At the Kurepa Plant, on the Teya, its section carries the same members as at the village of Teya, but they are thicker here (Fig. 2). At the base of the formation, the granites are overlain by gray arkosic sandstones, several tens of meters thick. To the west, on the Pravaya Uvolga and Garevskiy Creek watershed, coarse unsorted conglomerates with quartz and quartzite pebbles appear at the base of the formation. (Ye.V. Pokrovskiy).

It follows from the above description that, on the whole, the Chivida formation along the Teya River is subdivided into three members: the lower, dolomitic; the middle, argillaceous-arenaceous; and the upper, represented by flyschlike alternations of sandstones, argillites, and siltstones (Fig. 2). Resting conformably on the flyschlike member are red sandstones of the Namchana formation.

Only the flyschlike member persists along the Chapa River, whereas the lower part of the formation changes rapidly. At the mouth of Tayeznyy Creek, the base of the formation is represented by a 300 to 350 meter thick argillite-arenaceous member, similar to the middle member of the Chivida formation at the Teya River and resting unconformably on the Pogoryuysk meta-shales and quartzites. Its lower part carries beds of gray dolomites. This fact, as well as their stratigraphic position, makes it possible to correlate these rocks not only with the middle but also with the lower dolomitic member on Teya River (Fig. 2). At the mouth of Tayeznyy Creek, the Chivida formation is culminated in a flyschlike member, about 300 meters thick, overlain conformably by the Nemchana formation.

Higher up along the Chapa, at the mouth of the Chivida River,[3] the lower part of the Chivida formation, about 500 meters thick, is represented by greenish-gray to fadded cherry-colored argillites and siltstones, alternating every 5 to 10 centimeters. The lower part of this sequence carries dolomite beds, with a member of quartzitic sandstones in the upper part (Fig. 2). Above them, there are 500 meters of boulder-pebbly argillites, drab-gray, sandy, nonstratified, carrying pebbles and boulders of assorted carbonate rocks and subordinate gray and pink quartzites, dark phyllitic meta-shales, and in places of extrusive rocks. The section is capped by a flyschlike member, 200 meters thick, conformably overlain by sandstones of the Nemchana formation. The Chivida section at the mouth of the Suktal'ma does not appreciably differ from the one described above.

West of the Chapa River, along the Vorogovka, boulder-pebble argillites replace the entire Chivida section, with only isolated sandstone members present. Here, these argillites are intensively schistose; the pebbles increase both in size and in number (especially at the base of the formation by remnants of ancient relief), as compared with the Chapa River [4]. Judging from cross sections, the pebble-boulder argillites along the Vorogovka are several hundred meters thick.

North of the Vorogovka upper course, the Chivida formation is exposed only along the Bol'shaya Chernaya, above the mouth of the Bol'shaya Kolonka. Exposed in an isolated tectonic wedge, there are a 200 to 250 meter thick sequence of pebbly-boulder argillites and underlying bedded greenish-gray argillites and sandstones with lenses of conglomerates. Externally, the Bol'shaya Chernaya pebbly-boulder argillites are very similar to those along the Chapa; however, the composition of their pebbles is even more varied. Here,

[3] The Chivida formation section at the mouth of the Chivida River is given in the paper of V.N. Grigor'yev and M.A. Semikhatov [4], along with a detailed description of the section as it occurs southwest of there, including a description of the pebbly boulder argillites.

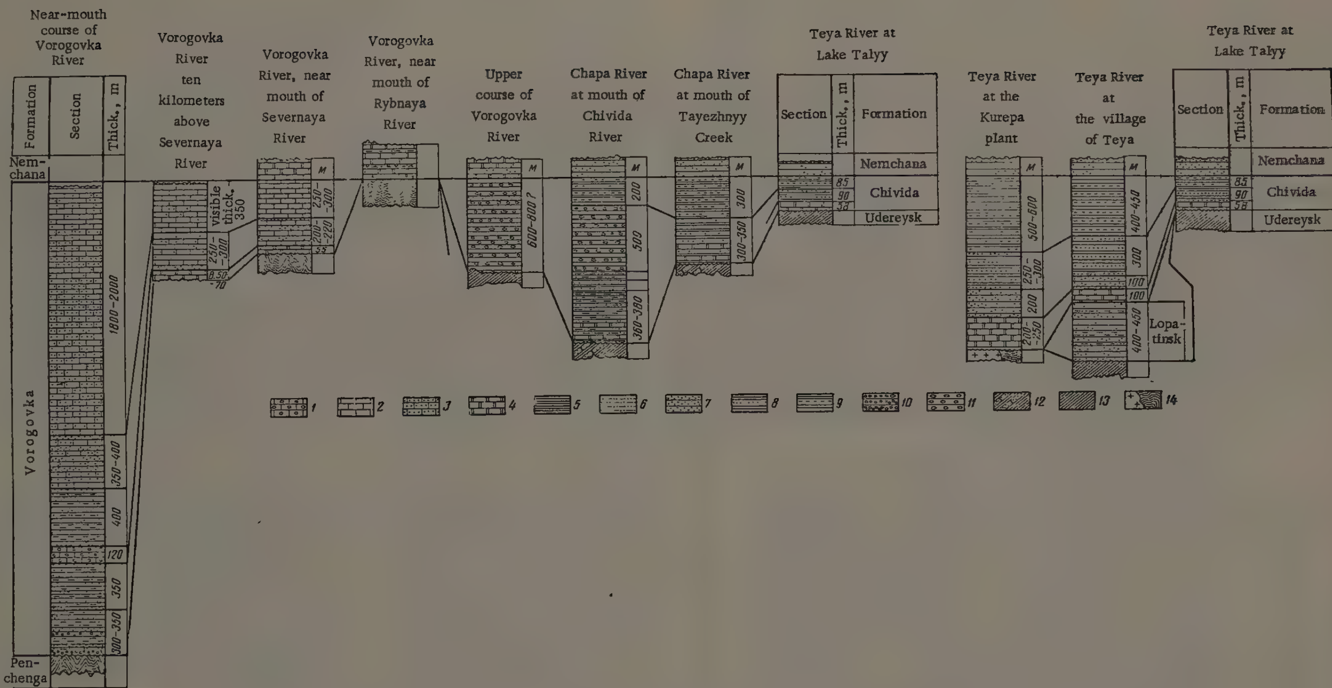


FIGURE 2. Correlation cross section of the Chivida and Vorogovka formations.

1 -- Lumpy (oncolitic) limestones; 2 -- limestones; 3 -- limestones with thin sandy intercalations; 4 -- dolomites; 5 -- argillites; 6 -- siltstones; 7 -- sandstones; 8 -- argillites with intercalations and lenses of sandstones; 9 -- flyschlike alternation of sandstones, 10 -- conglomerates; 11 -- boulder-pebble argillites; 12 -- Pogoryuysk formation: shales and phyllitelike meta-shales with quartzite intercalations; 13 -- Udereysk formation: shales and phyllitelike meta-shales; 14 -- crystalline schists of the Penchenga formation and granites.

over a distance of 300 meters along the strike, the sedimentary pebbles and boulders, which accounted for 85% to 95% of the total, are entirely replaced by pebbles and chunks of extrusive rocks (chiefly granites). There is a change in color from gray to orange.

To the west, in the basin of the Bol'shaya Lebyazh'ya River, along the middle course of the Vorogovka, and in the Rybnaya River basin, the Chivida formation drops out of the section, and the Precambrian is overlain by younger formations — the Nemchana and Lebyazh'ya.

The pebbly-boulder argillites were formerly described as tillites [1, 6, 8, 9], with most students assigning them to the Precambrian as a separate formation. Our study has confirmed the opinion of I.G. Nikolayev [8] of a facies relationship of these argillites (tillites) and the gray sandstones and argillites along the Teya and Chapa (greywacke of I.G. Nikolayev) and made possible their designation as a single formation. The new data has shown those pebbly-boulder argillaceous deposits to be of density-current and submarine-slide origin, rather than of glacial formation [4].

The Vorogovka formation is developed along the right bank of the Yenisey, south of the Karpinskiy Range anticlinorium. Its most easterly section is exposed along the Vorogovka, at the mouth of the Malaya Severnaya. Resting unconformably on crystalline schists of the Pechenga formation, are the following rocks (reading upward):

1. Dolomites, light gray, thin bedded in lower two meters, with intercalations of conglomerates, 5 to 10 centimeters thick, of poorly rounded pebbles of quartz and crystalline schists; growing thicker bedded above, with intercalations of gray siltstones; 55 m.

2. Limestones, light gray to brown-gray, with numerous thin (1 to 10 millimeters) laminae and lenses of calcareous, greenish-gray, polymictic sandstone. In addition, there are 0.2 to 0.5 meter thick layers of similar sandstones, every 0.5 to 1.5 meters; 200 to 220 meters.

3. Limestones similar to those below; upper 35 meters is brecciated; 250 to 300 meters.

The Vorogovka formation is 500 to 650 meters thick. It is overlain, with a gradual transition, by the Nemchana dolomites. The amount of sandstones in the middle member of the Vorogovka formation, along with the thickness of the entire formation, increases to the west (Fig. 2).

The most complex is the Vorogovka section along the Vorogovka River, below the mouth of the Mikheyeva River (reading upward, Fig. 2):

1. Siltstones, greenish-gray in the lower part and cherry red in the upper; interbedded with greenish-gray to cherry-red coarse-grained sandstones. In the middle part, there is a 30 meter thick body of conglomerates with poorly rounded pebbles of quartz and crystalline schists, 1 to 2 centimeters. Their thickness is about 300 meters. The contact of this member and the Pechanga formation is not exposed. It appears to be underlain by a 60 meter thick conglomerate member, with pebbles of crystalline schists and quartz, which rests unconformably on the Precambrian and is exposed in an isolated tectonic wedge, somewhat higher upstream along the Vorogovka.

2. Sandstones, greenish-gray, fine to medium grained, polymictic, calcareous, with lenses of quartz gravels and lentils and members of siltstones. In the middle part, there is a member of dark gray, essentially lumpy limestones (Fig. 2). About 850 to 900 meters thick.

3. An alternation of sandstones and banded limestones, as below; 350 to 400 meters.

4. Light-gray limestones, unevenly enriched in sandy material which concentrates in numerous lenticular and distinct intercalations, from 0.1 to 1.5 or 2 centimeters thick, extended along a single line. Visible thickness, 1,800 to 2,000 meters.

This section of the Vorogovka formation is 3,600 to 3,800 meters thick. Along the Yenisey, opposite the mouth of the Dubches River, it is conformably overlain by the Nemchana dolomites.

It appears from the above descriptions that the upper part of the Vorogovka formation, as exposed in various places, are fairly correlative with each other (Fig. 2). The lower part of the section is, on the other hand, different in the eastern and the western sections. It is possible that the 700 meter thick terrigenous sequence at the base of the formation, at the mouth of the Vorogovka River, is correlative not only with the lower Malaya Severnaya member but also includes the underlying Cambrian beds, missing in the east.

South of the Vorogovka, this formation is rapidly cut off by a series of faults; it reappears in the lower course of the Isakovka River. Here, the section is very similar to that at the mouth of the Vorogovka; its thickness, 3,000 to 3,200 meters. As in that locality, the formation is conformably overlain by the Nemchana formation.

The Vorogovka rocks were formerly described as components of the Cambrian and Silurian [8] and Lower Cambrian deposits (N.P. Verbitskaya, M.A. Apenko, F.F. Il'in). As a separate unit, this formation was recognized in 1949, by O.P. Goryainova and E.A. Fal'kova who assigned it to the Precambrian, on the basis of what they believed to be its unconformable position below the Lower Cambrian.[4] The new data make it possible to review the stratigraphic position of the Vorogovka formation.

As already mentioned, this formation is conformable upon the Udereysk and Penchenga formations, and is everywhere overlain conformably by the Nemchana formation. A gradual transition from the Vorogovka to Nemchana formation has been observed along the Vorogovka, at the mouth of the Malaya Severnaya.

Thus, in its stratigraphic position, the Vorogovka formation, developed southwest of the Karpinskiy Range anticlinorium is correlative with the Chivida formation to the northeast. In addition, this is confirmed by the following considerations. Rocks of the western sections of the Chivida and Vorogovka formations are indistinguishable externally and microscopically. The lower portion of both formations is represented in a number of sections by dolomites, with the upper portion represented by calcareous rocks and limestones. Finally, the rhythmic character of the alternation of various rocks in the Vorogovka formation is very similar to that of the Chivida formation.

The Nemchana formation is widely distributed in the area under study, on both sides of the Karpinskiy Range anticlinorium, also locally preserved at its crest.

Along the Teya River and at the mouth of the Pod"yem Creek, it is represented by cherry-red fine-grained sandstones, with intercalations of argillites and siltstones in its lower part. The sandstones are marked by cross bedding, swash marks, argillite pebble beds, and mud cracks. This formation is 1,000 to 1,100 meters thick.

Southwest and south of Lake Talyy, and at the mouth of the Pod"yem Creek, the amount of siltstones at the base of the Nemchana formation increases. Appearing among them, along the Madra River, are beds of gray to pink dolomites which merge into a single member going west (Chapa River, at the mouth of the Tayezhnyy Creek), where they are 200 to 250 meters thick (Fig. 3). Farther southwest, the amount of dolomites and siltstones continues to increase in the lower part of the formation; the following section is exposed along the Chapa, above the mouth of the Nemchana River (reading upward):

1. Sandstones, cherry red, fine grained, with siltstone intercalations; 250 to 300 meters.

2. Dolomites, light gray, with intercalations of gray fine-grained to gravelly sandstones; about 400 meters.

3. A rapid alternation of cherry-red argillites and siltstones, with sandstones higher up; 600 to 650 meters.

4. Sandstones, cherry red, similar to those described for Lake Talyy; 2,200 to 2,500 meters.

The total thickness of the Nemchana formation is 3,500 to 3,800 meters; as at the mouth of the Tayezhnyy Creek, it rests conformably on the Chivida flyschlike member and is overlain conformably by the Lebyazh'ya dolomites (Fig. 3).

In more southerly areas along the Teya and Chapa Rivers, the Lebyazh'ya formation and some part of the Nemchana formation have been washed out by recent erosion.

The upper member of the Nemchana formation has been preserved only in the upper course of the Chivida. At the village of Teya along the Teya River, the lower sandstone member, 200 to 250 meters thick, has been observed together with the overlying Nemchana dolomite member, also with a visible thickness of 200 to 250 meters. In the extreme southern exposures of this formation along the Teya at the Kurepa plant, the lower sandstone member and a lower part of the dolomite member are exposed.

It follows from what has been said that, going south from Lake Talyy, terrigenous rocks in the lower part of the Nemchana formation are replaced by dolomites. A further development of this replacement takes place in the upper course of the Chapa River. At the Suktal'ma mouth, red sandstones between the Chivida flyschlike formation and the Nemchana dolomites are only 100 meters thick, but they are missing along the Chapa, at the mouth of the Bol'shoy Almanakan River. Here, dolomites with rare layers of cherry-red sandstones and siltstones rest directly on the flyschlike member; their visible thickness is 800 to 850 meters. Considering, that at both the Bol'shoy Almanakan and the Suktal'ma, the dolomites rest conformably on underlying

[4] O.P. Goryainova and E.A. Fal'kova also assigned the terrigenous rocks of the Nemchana formation described below, to the Lower Cambrian of the right bank of the Yenisey.

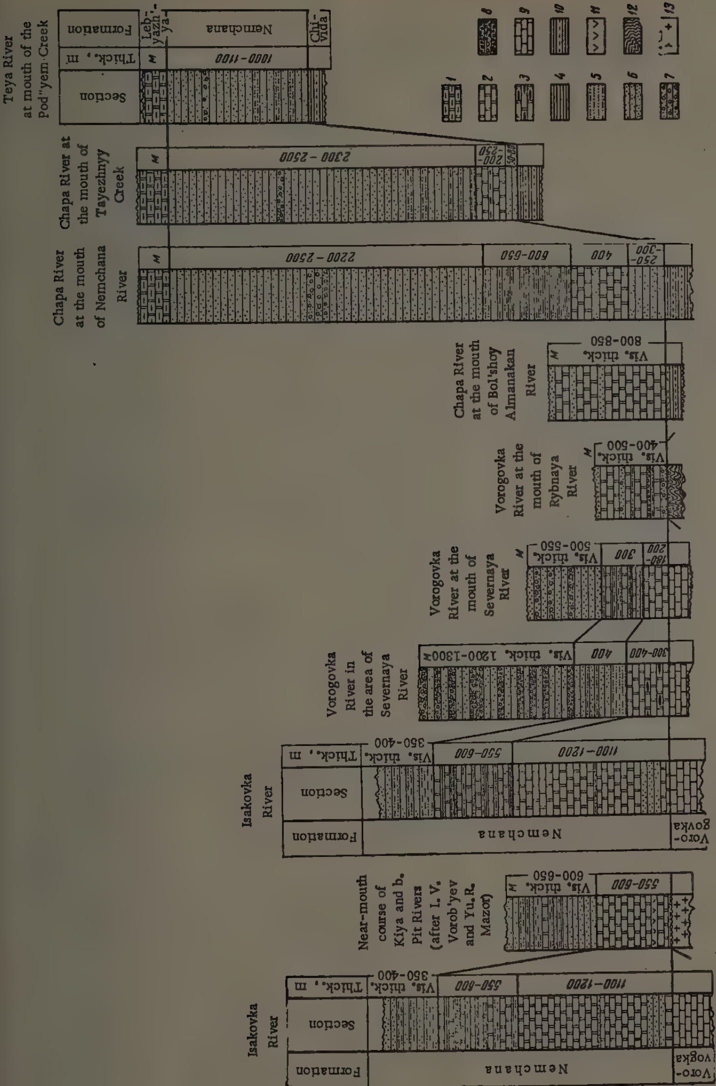


FIGURE 3. Correlation diagram for the Nemchana formation sections.

1 -- Lebyazh'ya dolomites; 2 -- Nemchana dolomites; 3 -- dolomites with cherts; 4 -- argillites; 5 -- siltstones; 6 -- sandstones; 7 -- sandstones with dispersed pebbles, and conglomerate beds; 8 -- conglomerates; 9 -- Vorogovka limestones; 10 -- flyschlike alternation of sandstones, siltstones, and argillites of the Chivida formation; 11 -- andesites, basalt porphyrites; 12 -- crystalline schists of the Penchinsk formation; 13 -- granites.

deposits, and that a gradual transition has been established between them by eluvium, the wedging-out of sandstones at the base of the Nemchana formation, in the upper course of the Chapa, can be explained only by their being gradually replaced by dolomites. Along the upper Vorogovka, the Nemchana dolomites rest directly on the Chivida pebbly gravel argillites, also without visible evidence of an unconformity [4, 9].

To the west, on the Vorogovka-Rybnaya watershed, and along the Vorogovka at its mouth, the Nemchana formation rests directly on the Penchenga crystalline schists; and on the Udereysk formation in the Kamenistaya River basin to the north. In the Kamenistaya basin, dolomites in the lower part of the Nemchana formation are replaced by terrigenous rocks, with 200 to 300 meters of cherry-red sandstones and conglomerates at its base.

The conglomerate pebbles are represented by quartz, quartzites, less commonly by red siltstones and in places by gray dolomites. The pebbles vary from 1 to 8 centimeters (usually 2 to 4 centimeters). An estimate of the Nemchana formation, here, is 1 to 1.5 kilometers. To the west, along the middle course of the Bol'shaya Lebyazh'ya, the Nemchana formation drops out of the section, and the Precambrian is overlain by the Lebyazh'ya formation.

In the lower course of the Vorogovka, the conformably bedded older Lower Cambrian deposits reappear underneath the Nemchana formation and its aspect changes somewhat. Resting on the Vorogovka limestone in a gradual transition with them, are the following rocks (reading upward):

1. Dolomites, gray to cream colored, thick bedded, brecciated in their lower part, with gray to cherry-colored sandy dolomites higher up; 180 to 200 meters.

2. Siltstones, cherry red to gray, with layers, lenses, and isolated members of dolomites similar to those below and with sandstone intercalations; 300 meters.

3. Sandstones, cherry red, fine to medium grained, with gravel beds; 500 to 550 meters.

The visible thickness of the Nemchana formation is 900 to 1,000 meters.

Down the Vorogovka, in the mouth area of the Severnaya River, the formation is similar to the above (Fig. 3). In the sandstones of its upper member, there are beds, 5 to 10 meters thick (in places as much as 30 m), of conglomerates with pebbles of quartz and less commonly of quartzites. The pebbles are well rounded, attaining 10 to 12 centimeters (usually 2 to 5 centimeters).

Along the Severnaya River and at its mouth, dolomites of the lower Nemchana member carry lenses and layers of black nodular cherts, as much as 20 meters thick.

West of the Severnaya, only the dolomitic Nemchana member is exposed. More complete sections of this formation are exposed at the mouth of the Kutukas River and in the lower course of the Isakovka. On the whole, the section here exhibits the same three members as along the lower Vorogovka, but of a greater thickness (Fig. 3). These sections, well tied together, are also reliably correlative with those on the other side of the Karpinskiy Range anticlinorium.

Indeed, a stratification sequence has been established in the Nemchana section on the right bank of the Yenisey, very similar to that in the upper courses of the Chapa and Vorogovka (Fig. 3), whereas rocks in the corresponding members, and the structural features of the members themselves, are the same in both sections.

South of the Isakovka River, the Nemchana deposits outcrop in the Tisa-Chernaya watershed (Fig. 1). Their best sections are exposed in the lower course of the Kiya and at the mouth of the Bol'shoy Pit River. According to I.V. Vorob'yev and Yu.R. Mazor, Precambrian granites along the Kiya River are overlain, with an erosional contact, by 500 to 600 meters of light gray to pink, thick-bedded dolomites with nodules of gray chert, and with isolated bedded bodies of andesites and basalt porphyrites in its lower part, along with intercalations of red argillites and sandstones. At the base, there is a 0.5 meter-thick bed of breccia-conglomerate with fragments of quartz, microcline, and mica, of 0.2 to 2 centimeter diameter. They are overlain by a sequence of red sandstones, subordinate siltstones, and argillites with a few intervening beds of conglomerates and dolomites; its visible thickness is more than 600 meters.

To the north, in the basins of the Vyatka and Tis Rivers, these deposits rest upon lower Proterozoic crystalline schists; their nature is similar to that described above (V.M. Chairkin, S.S. Gurvich).

It is clear from the above description that red terrigenous-carbonate deposits in the Tis-Chernaya watershed are very similar in their section to that of the Nemchana formation of the Isakovka and Vorogovka Rivers. Considering the increasing importance of dolomites in the middle Nemchana member, going from north to south (from Vorogovka to Isakovka), the Kiya River dolomites are most probably correlative with the lower (dolomitic) and middle (terrigenous-dolomitic) members of more northerly regions (Fig. 3).

The Lopatinsk, Chivida, and Nemchana formations have been separated within the Chapa formation as designated by geologists of the All-Union Aerogeological Trust. However, this differentiation is not yet valid for the entire area of the northern part of the Yenisey Range. It is therefore expedient to keep the name of Chapa for the superformation embracing these three formations.

The Lebyazh'ya formation caps the Lower Cambrian section in the northern part of the Yenisey Range. In agreement with V.N. Grigor'yev [2], we have succeeded in differentiating this formation, as exposed along the Teya River from Lake Talyy to the mouth of the Parnaya River into three members. The lower, about 500 meters thick, is made up

of gray thin-bedded dolomites. The middle, about 400 meters thick, is represented by alternating thick beds of gray dolomites and limestones interbedded with thin dark-gray dolomites. V.N. Grigor'yev has found remains of Bulaiaspis prima Lerm. [2] in its upper part. The upper member, about 300 meters thick, is represented by thin, yellowish-gray dolomites, with sandstones and siltstones near the top. Along the Teya River, at Lake Talyy, and along the Chapa at the mouth of the Tayezhnyy Creek, and near the Nemchana River, the Lebyazh'ya formation rests conformably on the Nemchana formation.

West of the Chapa, from the Listvennaya headwaters to the right bank of the Bol'shaya Lebyazh'ya, the lower Lebyazh'ya member is cut off by a large fault. The base of the formation is visible only along the Lebyazh'ya River. Here, the Chivida and Nemchana formations are missing, and the Lebyazh'ya formation rests with an angular unconformity directly upon the Udereysk shales (along the Bol'shaya Lebyazh'ya River, above the Mokraya; along the Severnyy Skvoznoy Creek, Malaya Lebyazh'ya, and — according to O.P. Goryainova, E.A. Fal'kova, and N.E. Shul'ts — in the Rybnaya headwaters and in the Rybnaya-Severnyy Skvoznoy-Malaya Lebyazh'ya watershed). In these areas, dolomites at the base of the formation are enriched by sandy material and contain light-gray to yellow sandstones. The latter locally carry scattered pebbles of quartz, quartzites, less commonly of carbonate rocks and the Udereysk shales, diameter 0.5 to 1.5 centimeter.

The presence of Bulaiaspis prima Lerm. in the middle member suggests that the latter belongs to the Tolchansk bed of the Lena stage [2]. From its stratigraphic position, the upper member of this formation may be assigned to the Olekma and possibly to the Ketemensk beds. This is confirmed by the lithological similarity of this member to the Agelevsk formation of the lower Angara region, whose association with these beds has been proven paleontologically [2, 10]. The lower Lebyazh'ya member may be tentatively assigned to the Sinsk of the Lena stage. The underlying Nemchana, Chivida, and Lopatinsk formations are not separated from each other and from the Lebyazh'ya formations by angular unconformities, but form a discrete sedimentary cycle; all four formations have been dislocated and metamorphosed to the same degree — therein lies their sharp difference from the underlying formations upon which they rest with an angular unconformity and a deep erosional break. This makes it possible to assign the Lopatinsk, Chivida, its correlative Vorogovka formation, and the Nemchana formation, to the Lower Cambrian Aldan stage. In their stratigraphic position, composition, and the sequence of strata, the Lopatinsk, Chivida, and Nemchana formations are quite correlative, respectively, with the Koval'sk, Aleshinsk, and Shalyginsk formations of the lower Angara region, which belong to the Aldan stage [10].

## GEOLOGIC HISTORY OF THE EARLY CAMBRIAN AND PROBLEMS OF PALEOSTRUCTURAL DIFFERENTIATION OF THIS EPOCH INTO REGIONS

Data on the Precambrian history of this area are very scarce. Considering that the Lower Cambrian rests with an angular unconformity on various Precambrian formations and granites, a folding may be assumed at the end of the Proterozoic, with intrusions, a subsequent uplift, and a deep erosion.

The onset of the Cambrian witnessed the initiation of two troughs in the northern part of the Yenisey Range, and an uplift separating them. The Lopatinsk and Chivida formations were deposited in the eastern — the Teya — trough; the Vorogovka formation was deposited in the Yenisey trough, to the west. The Teya trough, as witness the distribution of facies and of thicknesses of the lower part of the Aladan stage, was located on the site of the present basins of the Teya, Chapa, and Bol'shaya Chernaya Rivers, and had a northwestern trend; its axis extended from the Kurepa Plant to the Bol'shaya Kolonka headwaters. Northeast of this line, the Chivida formation thins to 230 meters at Lake Talyy and even more, farther east. According to G.A. Kudryavtsev, at the Korda headwaters the Chapa superformation is not more than 250 meters thick. Thus, in Chivida time, the Teya trough was bounded in the east by a comparatively uplifted province.

Southwest of the Teya trough axis, the Chivida formation also becomes thinner, but the data on this thinning is meager. The western boundary of the trough and the structure fringing it are more reliably established from the following considerations. There is a narrow meridional belt in the middle course of the Vorogovka and along the Bol'shaya and Malaya Lebyazh'ya Rivers, where lower beds of the Lower Cambrian are missing in the section, and the Nemchana and Lebyazh'ya formations rest directly on the Precambrian. A wide band of pebble boulder argillites stretches along this belt, within the Teya trough. These argillites represent littoral marine deposits which were laid down at the foot of an uplift and then spread over considerable distances as a result of density currents and submarine slumps [4].

Thus, at the beginning of the Aldan age, the Teya trough was fringed in the west by a narrow zone of uplifts which stretched generally from north to south along the present meridional stretch of Bol'shaya Lebyazh'ya and farther on to the sources of the Isakovka and Vorogovka Rivers. Farther south, on the Uvolga-Garevka watershed, coarse conglomerates appear at the base of the Chivida formation; I.G. Nikolayev [9] mentions rocks similar to the pebble-boulder argillites ("tillites") of the Vorogovka, in the Tis headwaters, along the Olen'ka River. Still farther south, on the Tis-Chernaya watershed, the lower Aldan beds are missing and, as is the case along the middle Vorogovka course, the Precambrian is overlain by the Nemchana formation. All this makes it possible to trace this zone of uplifts from the Vorogovka sources south to the middle course of the Tis and to the mouths of the Kiya and Bol'shoy Pit Rivers (Fig. 4). We have named this uplift, the Kiya-Lebyazh'ya.

The Yenisey uplift was located at the onset of the Aldan time west of the Kiya-Lebyazh'ya uplift. This is suggested by the appearance of the Vorogovka formation under the Nemchana formation in the section along the Yenisey right bank, and by its rapid thickening from east to west. The western boundary of this trough is not known with certainty. The increase in terrigenous material in the Vorogovka formation, going west, suggests the presence of an early Aldan uplift in the Yenisey left-bank area; and that the uplift bounded the Yenisey trough in the west and was a source of its clastic material. This conclusion is in agreement with that of G.I. Kirichenko [6] to the effect that the western boundary of a Lower Cambrian uplift, located on the site of the Yenisey Range, lies within the western boundary of the west Siberian plain.

Mention has been made that density currents played a large part in the shifting of the Chivida sediments and that submarine slump folds are widely developed in the Chivida and Vorogovka formations. Such processes could have been developed only with appreciable dips of the basin bottom. In other words, the accumulation of the Vorogovka and Chivida formations did not compensate for downwarping of the basin bottom, and there were considerable depths present in near-axial parts of the Teya and Yenisey troughs in Chivida time. This conclusion is confirmed by the facies type of deposits found in these formations.

Nemchana time witnessed the development of structures inherited from the first half of Aldan time. The Teya trough underwent a subsidence, as much as 4 kilometers. Despite such active downwarping it was fully compensated for by sedimentation, as shown by evidence of a shallow-water deposition throughout the entire Nemchana formation. Going from the near-axial parts of the Teya trough to its eastern border, the thickness of the Nemchana formation decreases from 3,600 to 3,800 meters (Chapa River at the mouth of the Nemchana River) to 1,000 to 1,100 meters (Teya River, at the mouth of Pod"yem Creek), and even more at the Korda headwaters. Thus, a relatively uplifted province persisted in Nemchana time in the Vel'mo and Korda headwaters, east of the Teya trough and constituting its boundary. Its western boundary, as before, was the Kiya-Lebyazh'ya uplift. Its existence in the north of the area, in the Nemchana time, is established from a transgressive position of the Lebyazh'ya formation over the Precambrian in the Rybnaya-Bol'shaya Lebyazh'ya basin; from the thinning of the Nemchana formation in the Bol'shaya Lebyazh'ya basin; and from the appearance of conglomerates at its base, in the Kamenistaya basin. The lower part of the Nemchana formation is much thinner along the Kiy than along the Isakovka, and is more like that along the Vorogovka, at the Malaya Severnaya mouth — the region located on the limb of the Kiya-Lebyazh'ya uplift. In other words, the southern part of that uplift, too, persisted as a positive structure in Nemchana time.

West of the Kiya-Lebyazh'ya uplift, the Nemchana formation rapidly becomes thicker, suggesting a continuous development of the Yenisey trough, during Nemchana time. The uplift, assumed to be present west of there, in Chivida time, was active in the second half of the Aldan stage. Related to it are the conglomerates in the upper Nemchana formation along the Vorogovka lower course. In more easterly sections (Teya and Chapa Rivers), only the "tails" of these conglomerates are present in the top of the Nemchana formation. They obviously reflect brief intensifications of upward movements in the source area.

Because of the small area of the present distribution of the Lebyazh'ya formation, the data on the geologic history of the area in Lena time, are scarce. Most probably, the Lower Cambrian transgression attained its maximum in the beginning of that time, with its end witnessing a change from marine conditions to continental.

In the present structure of the Yenisey Range, only small areas of these Lower Cambrian structures are exposed (Fig. 4). Their northern extension is concealed under younger sediments. Most of the Yenisey trough lies under the Mesozoic-Cenozoic West-Siberian plain, with only the area of its eastern edge accessible to study, in the Porozhikha-Tis watershed. To the south, a

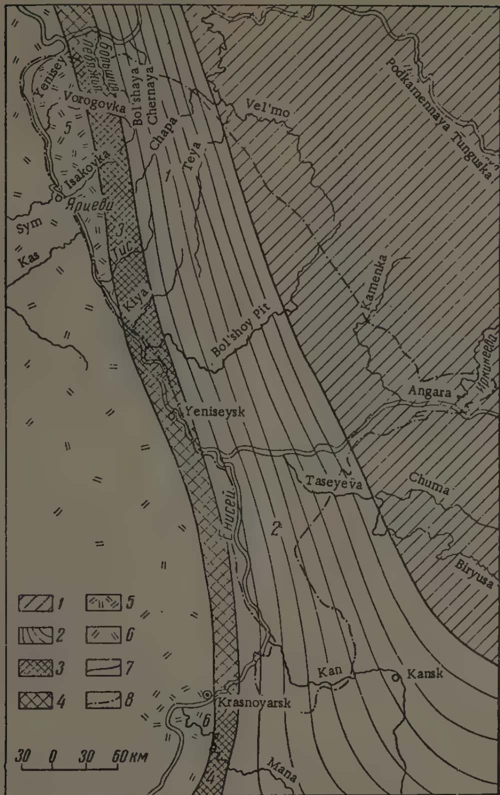


FIGURE 4. Distribution map of main structural elements of the Yenisey Range and the adjacent regions, in the Lower Cambrian.

Legend numbers: 1 -- platform; 2 -- outer zone of a miogeosyncline; 3 -- geanticlinal uplift; 4 -- geanticlinal uplift; 4 -- an assumed geanticlinal uplift; 5 -- interior zone of miogeosyncline; 6 -- assumed outer zone of miogeosyncline; 7 -- tentative boundaries of main structural elements; 8 -- present outline of the Yenisey Range on the base of post-Lower Cambrian deposits.

Numbers on map: 1 -- the Teya trough; 2 -- Angara-Kana trough; 3 -- Kiy-Lebyazh'ya trough; 4 -- Beret' uplift; 5 -- Near-Yenisey trough; 6 -- Ust'-Mana trough.

zone of faults, bounding the Yenisey Range in the west, cuts obliquely across the entire Yenisey trough, as well as the Kiy-Lebyazh'ya uplift, south of the Bol'shoy Pit River. There is no doubt, however, that these structures, in the Lower Cambrian, extended farther south.

There are direct data on a southerly extension of the Teya trough. In the near-Angara part of the Yenisey Range, directly on the extension of the Teya trough, there existed in the Lower Cambrian the so-called Angara-Kana trough [11] which stretched from the Eastern Sayans northern foothills and the

upper Mana basin to the city of Kansk and farther on to the lower course of the Taseyeva River, on to the Angara and to its right bank region [10, 12]. Deposits of the Koval'sk, Aleshinsk, and Shal'ginsk formations, which fill this trough, are quite similar to their correlative Lopatinsk, Chivida, and Nemchana formations, respectively, in their material composition, formation character, and stratigraphic sequence. Especially great is the similarity in eastern sections of the Aldan stage to its extreme western sections in the Angara region. East of the latter, in the lower Angara region, the Aldan and apparently the Lena stage thin abruptly, reflecting a transition from the trough to the Lower Cambrian Siberian platform [10, 12]. Over the latter, the Aldan stage is not more than 250 to 350 meters thick, with a thickness gradient of only 2 to 7 meters per kilometer, [10], whereas it attains 80 meters per kilometer within the Teya trough.

A zone of reduced thickness of the Lower Cambrian, which may be regarded as a boundary between the platform and the trough, is traceable from the vicinity of Aban Village, in the southeast, to the confluence of the Chuna and Biryusa Rivers, and farther on to the Angara and Bol'shoy Pit Rivers, between the mouth of the Gorbilok Creek and Pit-Gorodok Settlement [10]. The above-mentioned relatively uplifted area of the Korda and Vel'mo headwaters corresponds to more northerly reaches of the same platform.

Thus the Angara-Kana and the Teya troughs are components of a single downwarp which fringed the Siberian platform from southwest and west in the Lower Cambrian. At the present time, this structure is traceable from the Eastern Sayan foothills (the Mana, Biryusa, and Uda basins; [10, 12]) to the Podkamennaya Tunguska, a distance of 700 kilometers. There is no evidence of a closure in this structure over that distance; it may be assumed, therefore, that it continues beyond our area. On its outer side, relative to the platform, this trough is bounded by a narrow uplift of a geanticlinal type. It has been described above only for the northern part of the Yenisey Range; however, there are reasons to believe that it existed in areas to the south.

In this connection, of great interest is a meridional uplift in the Mana basin (western part of Eastern Sayan), recently described by V.V. Khomentovskiy [12]. This uplift may be named the Beret' — after a river of that name which flows within it. It presents a northern — and apparently the main — stem of the East-Sayan anticlinorium, and divides the Cambrian Mana synclinorium. The western part, the so-called Ust'-Mana syncline, differs from the eastern (Solbinsk and Zherzhul'sk synclines) in the more complex structure of its Cambrian sequences, their greater thicknesses, the abundance of intrusions, and in the appearance of Cambrian extrusives. Thus, the Beret' uplift, like the Kiya-Lebyazh'ya, separates an early Cambrian near-platform trough from another one to the west.

Besides the similarity in their structural position, these uplifts are marked by similarity in their development. During the entire Lower Cambrian, they both existed as positive forms of the first order and controlled the distribution of facies and thicknesses; in the first half of the Aldan age, they were a source of sediments, with thick tillitelike conglomerates accumulating at their base. It should be emphasized that the trend of these two structures nearly coincided, so that geographically they were, roughly, a continuation of each other.

In view of the above, it is very probable that the Kiya-Lebyazh'ya uplift of southern areas is present here as the Beret' uplift (Fig. 4). The outline and position of the latter are determined by a zone of faults, which is a northern branch of the major deep-seated East-Sayan faults [12]. It may be assumed, then, that the northern part of this uplift was controlled by a deep-seated fault. This view explains its great linear extent and its small width. Unfortunately, this conclusion cannot be confirmed by a structural analysis of the northern part of the Yenisey Range, because Cambrian and Proterozoic faults here have practically not been studied at all, and because they are camouflaged by numerous, much younger faults which cut obliquely across the ancient structural-facies zones.

The Ust'-Mana and the Yenisey troughs, west of this geanticlinal zone, apparently belonged to a single downwarp located farther inside the lower Paleozoic geosyncline.

The above-named differences in the composition and structure of the Lower Cambrian Angara-Kana and Teya troughs on one hand, and of the Ust'-Mana and the Yenisey troughs on the other, are obviously inadequate to contrast their tectonic nature, to any extent. In the formational aspect of Lower Cambrian sequences, in their stratigraphic extent, and in the pattern of their facies change, all of these structures are very similar. This similarity is especially clear if we compare the above-named features of the Mana trough Cambrian, as a whole, and of the so-called Sisim synclinorium — a typical eugosyncline located on the southern slope of East Sayan. After having analysed the development features of that eugeosyncline, and of the mana trough as a component of the Angara-Kana trough,

V.V. Khomentovskiy [12] has convincingly proved the miogeosynclinal nature of the latter. On the other hand, a number of investigators regard this structure as a foredeep, chiefly referring to the fact that it is in direct contact with the platform in the east, and that it is filled with terrigenous (chiefly red) and carbonate (locally salt bearing) deposits; also that igenous activity within it is very small.

We shall now inquire as to which of these two views is supported by actual data from the northern part of the Yenisey Range.

The vast Lower Cambrian trough, which included the Ust'-Mana and the Yenisey troughs, undoubtedly belongs to geosynclinal structures. This is suggested by the intensive folding of its sediments, their great thicknesses, high gradients of the thickness change (as much as 120 m/km for the Aldan stage in the Yenisey trough), the presence of large post-Lower Cambrian granite intrusions in the Ust'-Mana syncline, etc. Since extrusive formations are virtually lacking in this trough, it should be regarded as a miogeosyncline in M. Kay's terminology [7]. As we have mentioned, the Teya trough, adjacent to it in the east, was initiated and developed simultaneously with this miogeosyncline, undegoing nearly as intensive and as contrasting subsidences. The development of both the Teya and Yenisey troughs appears to have terminated at the same time, because the Middle Cambrian is unknown within them, whereas the Upper Cambrian and the Ordovician rest unconformably and make up the next structural stage.

Is it possible, in the light of the above considerations, to assign the Teya trough to a foredeep type? Foredeeps are known to originate and to develop along the edges of platforms and geosynclines, at a time of the latter's closing, general uplift, and transformation into mountain structures. Nothing of the sort has been observed in our instance. The epoch of the most active development of the Teya trough within the Yenisey downwarp, which was located toward the interior of a geosynclinal province, was marked by an even more intensive subsidence. The Kiya-Lebyazh'ya uplift, which bounded the Teya trough from the outside, relative to the platform, not only did not grow larger in the course of its geologic history, as should have been the case in the instance of a foredeep, but it actually did grow smaller. By the second half of the Aldan age, it no longer was a source of clastic material for the Teya trough, as it has been in the beginning of that period; the uplift appears to have stood barely above sea level and apparently was totally submerged in Lena time.

The concept of a platform nature for the Teya trough is contradicted by the immense thicknesses (6 kilometers) of its contained Lower Cambrian, the very high thickness gradients (as much as 80 m/km) suggesting the range of its tectonic movements, the presence of flysch, etc.

It appears that for tll these reasons, the Teya trough, together with the Yenisey trough, should be assigned to miogeosynclines. Considering the spatial distribution of these troughs and their structural individuality, the Teya and Angara-Kana troughs may be regarded as an outer, near-platform zone of a miogeosyncline, and the Yenisey and the Ust'-Mana troughs its interior zone. We have previously discussed the difference between these two zones.

In conclusion we emphasize that these uplifts and troughs are elements of the Lower Cambrian structure of the area. Its modern structure has originated in much later horst-anticlinal uplifts which separated the segments of Lower Cambrian structures, reshaped them to a considerable extent, and brought them to the surface.

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Geological Institute,
Academy of Sciences, U.S.S.R.
Moscow

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# SILURIAN DEPOSITS OF THE KARGABULAK SPRINGS AREA[1]

by

N. G. Markova

Silurian deposits of the Bet-Pak-Dala and western Balkhash Region are, as yet, little known. Not only is there no general classification for this vast area, but even well-substantiated paleontologic sections are a rarity. The only section that may be called standard is known from near the settlement at Mynaral and the Ak-Kerme Peninsula, where it was recently described by B.M. Keller [1], also by B.M. Keller, I.N. Krylov, and Ye.V. Negrey [2]. Because of this, any material analysed in some detail, is of interest. This is why we deem it necessary to publish material on the Kargabulak Springs area, gathered in the summer of 1955, in the course of work on stratigraphy. This area was previously visited and mapped by B.I. Borsuk (1939), E.K. Vil'tsing, and I.T. Serebryakova (1952), M.A. Zhukov (1952), also by S.B. Bakirov and V.I. Volobuyev (1954).

According to our observations, Silurian deposits are developed here over a very small area (1.5 x 3.5 kilometers) where they form the rim of a synclinal structure representing the northeast terminal of the so-called Akzhar-Sarytum Carboniferous trough. In the southwest, the Silurian rests unconformably on the Rhiphean and Cambrian; in the south and northeast, it is in fault contact with the Ordovician and with Devonian volcanics. The lowest Devonian beds also fill the central part of this synclinal structure (Fig. 1).

According to our data, the Silurian section is as follows:

Its base is made up of dark gray, hematitic, commonly violet to spotted porphyrites ($S_1^a$) of an andesitic to basaltic composition. Along with pyroxene andesite porphyrites, there is a considerable amount of basalt porphyrites with olivine relicts. Less conspicuous are biotite and hornblende porphyrites, also clastic formations — tuffs and agglomerates; thin sandstones are present in upper beds.

The porphyrites are widely distributed over the southwestern limb of the trough where, as shown on Figure 1, they extend northwest from the Tyul'kul' saline area, and rest unconformably on the Cambrian and Rhiphean. Their thickness reaches about 300 meters.

The next formation ($S_1^b$), is considerably thinner (150 to 180 meters), is made up of light gray to yellowish, at times pink, usually tuffaceous sandstones, well stratified and thin bedded. They carry subordinate tuffs and ash tuffs of acid extrusives, with porphyrites at the base, quite similar to those below. Thus, the transition between the two lower formations is gradual. We shall cite specific instances of this Silurian interval which we assign to the lower division of the system. One of them, traced between Cambrian outcrops and Mesozoic-Cenozoic pebble beds which cover considerable areas south of the so-called second Carboniferous structure, presents the following section.

Cm 1. Green, strongly disturbed chlorite schists, cut by numerous quartz veins. A thick body of rock.

$S_1^a$ 2. Rocky outcrops of andesite porphyrites with conspicuous spicules of hornblende and incrustations of plagioclase. The rock is hematitic, purple-gray; 30 to 35 meters.

$S_1^a$ 3. Going farther northeast, outcrops of the same andesite porphyries occur continuously in the low bare summits. Locally, they are represented by better crystallized varieties with incrustations of dark minerals and plagioclase, in places by tough, strongly hematitic rocks; 260 meters.

4. A granite porphyry dike, of a variable trend, very thick, 30 to 40 meters.

[1] Siluriyskiye otlozheniya rayona rodnika kargabulak.

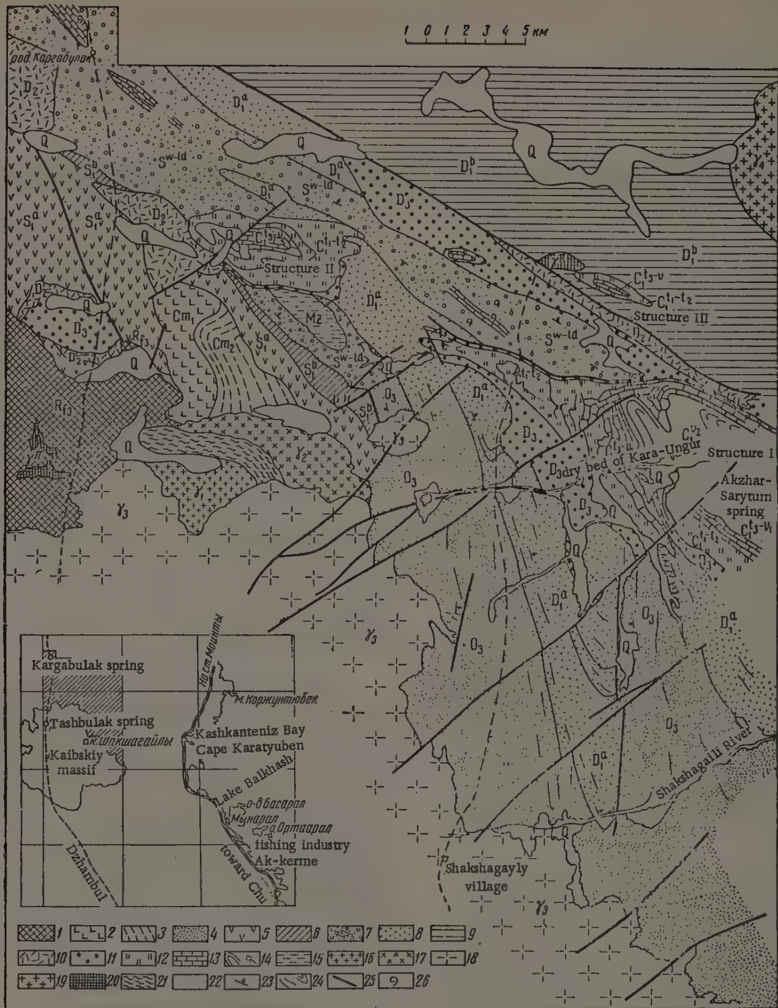


FIGURE 1. Geologic structure of the Kargabulak-Shakshagayly areas (N.G. Markova, 1956)

1 -- Upper Rhiphean ($Rf_3$) metamorphic sandstones; 2 -- Lower Cambrian ($Cm_1$) diabase porphyrites, their tuffs, lenses of "sealing wax" jaspers; 3 -- Middle Cambrian ($Cm_2$) quartz-chlorite schists and sandstones; 4 -- Upper Ordovician ($O_3$) dark-colored sandstones, gravels, siliceous siltstones; 5 -- Lower Silurian ($S_1^a$) andesitic and basaltic porphyrites; 6 -- Lower Silurian ($S_1^b$) tuffaceous sandstones with acid extrusives; 7 -- Silurian (Wenlock-Ludlow $S^{w-ld}$) reddish conglomerates, sandstones, siltstones, and argillites; lenses and massive bodies of reef limestones; 8 -- Lower Devonian ($D_1^a$) gray-green sandstones with subordinate basic to acid extrusives; 9 -- Lower Devonian ($D_1^b$) andesite porphyrites, with albitophyres, liparitic porphyries, and their tuffs; 10 -- Middle Devonian ($D_2$); 11 -- Upper Devonian ($D_3$) motley conglomerates and sandstones; 12 -- Lower Carboniferous ($C_1^{t_1-t_2}$) limestones, siliceous limestones, marls, red siltstones and sandstones; 13 -- Lower Carboniferous ($C_1^{t_3-V_1}$) dark-gray argillaceous siliceous limestones with sandstone beds; 14 -- Lower Carboniferous ($C_1^{V_2}$) green sandstones, conglomeratic sandstones, siltstones; 15 -- Mesozoic pebble beds; 16 -- gneissoid granites ($\gamma_1$); 17 -- diorites, quartz diorites, and plagiodiorites ($\gamma_2$); 18 -- the Kaib intrusion granites ($\gamma_3$); 19 -- porphyritic granite-syenites ($\gamma_4$); 20 -- granite-porphyries ($\gamma\pi$); 21 -- zone of dikes and quartz veins; 22 -- alluvium (Q); 23 -- strike and dip of rocks; 24 -- strike of rocks; 25 -- faults; 26 -- fossil sites.

$S_1^b$ 5. Dark red tuffs of plagioporphyries, with a dense ashlike groundmass and conchoidal fracture; 35 meters.

$S_1^b$ 6. Tuffaceous sandstones, yellowish-gray, dense; 50 meters.

$S_1^b$ 7. Andesite porphyrites, like those described above; 10 meters.

$S_1^b$ 8. Sandstones, similar to member 5; 50 meters.

$S_1^b$ 9. Tuffs of plagioporphyries, outcropping in a distinct ridge; 20 meters.

10. Outcrops of higher Silurian beds.

The following section with a better and more complete exposure of ($S_1^a$) and with a not as well-exposed overlying bed ($S_1^b$) has been traced approximately 4.5 kilometers south of the first exposure.

$S_1^a$ 1. Blocks and outcrops of black, dense basalt porphyrites, very tough, with indistinct incrustations, outcropping in a small bare hillock on the southeastern edge of the Tyul'kul' saline; 80 meters.

$S_1^a$ 2. Motley agglomeratic tuffs of porphyrites, unevenly hematitic and epidotic; 25 meters.

$S_1^a$ 3. Green amygdaloid porphyries, with cavities filled with chlorite and carbonate; 20 meters.

$S_1^a$ 4. Rocky outcrops of agglomeratic tuffs and porphyrites, similar to member 2; 35 meters.

$S_1^a$ 5. Sandstones, uneven-grained, gray-green, with fragments of basalt porphyrites; 10 meters.

$S_1^a$ 6. Porphyrites, andesitic, hornblende-plagioclase to pyroxene-plagioclase, alternating; 150 meters.

$S_1^b$ 7. Outcrops and lumps of compact fine-grained sandstone, adjacent to small dry mud flat; 30 meters.

$S_1^b$ 8. Red tuff of plagioporphyry, similar to that of member 5 in the preceding section; 30 meters.

$S_1^b$ 9. Reddish, fine-grained, well-stratified sandstones; 30 meters.

10. Sodded over; 50 meters.

$S_1^b$ 11. Sandstones, brown to reddish, similar to member 8; 20 meters.

12. Sodded over; 30 meters.

$S_1^b$ 13. A conspicuous ridge of red plagioporphyry tuffs which are a continuation of member 9 on the preceding section; 15 meters.

Resting on this section with an erosional contact, is the next Silurian formation, belonging to the Upper Silurian, as we shall see. This formation is marked by its varied composition and facies inconsistency over short distances, Developed here are brown-red to "chocolate", usually arkosic sandstones, locally gray to greenish; also red to green argillites with a typical "pencil" parting; limestones, gray, pink, and mottled, forming lenses and rapidly wedging-out lentils; locally in larger bodies; finally, conglomerates of large boulders and pebbles chiefly of the same limestone, also of underlying rocks. Present among these clastic formations, are subordinate beds of volcanic material represented by quartz to quartz-free varieties of plagioporphyries, their tuffs, and tuff breccias.

Conglomerates and limestones are usually predominant in the lower part of the formation, about 150 meters thick, with finer-textured rocks — siltstones and argillites — prevailing in the upper 200 to 230 meters. Thus the overall thickness of the formation is about 350 meters. The volcanic rocks are unevenly distributed throughout it, being better developed in the southwestern flank of the trough and only as isolated instances in the northeastern flank. On the whole, sections on the two flanks are not quite correlative, because of certain facies changes.

For illustration, we cite specific sections of the northern red formation, as we shall call it.

Very representative in the southwestern limb is a section which is a continuation of the second section of the Lower Silurian, previously discussed; this section correlates well with the latter and with a section to the north. Resting directly on porphyries of bed $S_1^b$ (members 9 and 13), there are the following:

1. Conglomerates with pebbles of gray to pink, mottled limestone and of gray sandstone; they outcrop in flat floorlike slaps; 20 meters.

2. Outcrops of quartz plagioporphyry tuff; 5 meters.

3. Sandstones, brown to chocolate colored, with fragments of porphyries; 5 meters.

4. Purple tuff of quartz plagioporphyry, in thin plates, 1 to 3 centimeters; 3 meters.

5. Loose gravel of conglomerate similar to

member one. There is no doubt but that a conglomerate bed occurs here. Especially numerous are limestone pebbles which also attain the largest size; 90 meters.

6. An alternation of quartz plagioporphyries tuffs and of chocolate-colored siltstones; 30 meters.

7. Light-gray sandstones consisting of reworked plagioporphyry material; 2 meters.

8. Sodded over; 20 meters.

9. Tuff of quartz plagioporphyry, reddish-brown; 3 meters.

10. Sandstone, red-brown to "chocolate", with fragments of quartz, feldspar, and acid and basic extrusives; 2 meters.

11. Thin-bedded siltstone, chocolate colored; 25 meters.

12. Small ridges of siliceous argillaceous red-brown argillite; 2 meters.

13. Sandstones, brown to chocolate; 10 meters.

14. Similar sandstones with fragments of red argillites, and thin intercalations of subordinate greenish-gray andesite porphyrites with small incrustations of plagioclase. Strike 320°, dip N. 40. E. Total thickness of this member is 80 meters.

15. Sandstones, red-brown, cut by a quartz vein; 30 meters.

16. A ridge of ashlike porphyry tuffs and "chocolate" sandstones. The strike, 310° to 320°, dip, N. 60° E. The ridge is shifted to northeast by a fault; 8 meters.

17. Ridges of chocolate sandstones; 20 meters.

18. Devonian outcrops.

19. A section of the same formation in the northeastern flank of the trough is somewhat different because of a sharp curtailment of volcanic rocks which are almost absent there. On the other hand, the sedimentary sequence is better represented; specifically, there appear lentils and lenses of limestones with faunal remains; near the top there is a considerable thickness of argillites. This flank of the trough has been affected by additional folding, resulting in dips of 50° to 60°. This should be taken into account in considering the section, because it leads to repetition of a number of beds.

We observed the best and the most complete section of this formation in the area of the northwestern terminal of the Akzhar-Sarytum Carboniferous trough. Here, near a road to the north to the so-called third Carboniferous structure, we observed the following section, just beyond the fault line:

1. Red to greenish siltstones, strongly disturbed and fractured; 30 meters.

2. Coarse-grained gray-green sandstone, changing to a small-pebble, locally, boulder conglomerate with abundant pebbles of pink, mottled limestone with a fauna of crinoids and small brachiopods; the pebbles attain 15 centimeters and commonly as much as 50 centimeters in diameter. In addition, there are smaller pebbles of granites and of red to green argillites; 20 meters.

3. Red, thin-bedded argillites; 10 meters.

4. Porphyry tuff breccia with coarse lapilli of plagioporphyry, as much as 30 centimeters in diameter, and with a red-brown cement of plagioclase, sericite, and carbonates, strongly compressed and schistose; 15 meters.

5. A sodded-over area with lumps of red-brown thick-bedded sandstones; 20 meters.

6. A boulder conglomerate producing good rocky outcrops; cemented with fine sand, little in volume. For this reason, the conglomerate consists mostly of boulders, 10 to 30 centimeters in diameter, of red to black plagioporphyries, limestones, to a smaller extent of granite-aplites; 20 meters.

7. Sandstones, reddish-brown to pink, coarse-grained, arkosic, with intercalations of greenish-gray platy sandstones and reddish to greenish thin-bedded argillites; 30 meters.

8. Conglomerate of small pebbles of porphyries, etc., with a lenticular layer, 1 to 3 meters thick, of a crystalline, crinoid limestone; 15 to 20 meters.

9. Pinkish-gray, fine-grained and thin-bedded sandstone interbedded with gray calcareous shales; 30 meters.

10. Gray, tough sandstone, changing farther on to outcrops of a fine-gravel conglomerate with pebbles of pink mottled limestone, granite, and red "sealing wax" jasper. The coarsest pebbles are 5 to 10 centimeters in diameter; small pebbles are more common; 20 meters.

11. Small ridges of gray, greenish to pink platy sandstone; 20 meters.

12. Red thin-bedded argillites; 10 meters.

13. Gray-green to red-brown "chocolate"

sandstones, with a well-expressed cleavage; 20 meters.

14. "Chocolate" siltstones with subordinate thin-bedded red argillites.

15. Greenish-gray thin-bedded argillites with a typical pencil parting; 30 meters.

16. Interbedded red-brown and greenish thin-bedded argillites; 80 meters.

Eight kilometers northwest along the strike, the limestone layer in conglomerates becomes thicker, as much as 5 meters, locally as much as 10 meters. Because of this, the limestones form isolated hillocks. This inconsistent limestone layer, essentially a chain of lenses, was traced over a distance of about 6 kilometers. It can be observed locally that some of the lenses change along the strike to a limy conglomerate, almost without cement and consisting of chunks of the same limestone. Farther on, the conglomerate is enriched by more diversified pebbles; however, even there the limestone pebbles predominate and attain the larger size. Still farther on, the conglomerate pebbles become smaller, finally changing to red-brown and "chocolate" sandstones. Thus the facies inconsistency of this formation is obvious and can be traced step-by-step.

We have collected a fauna of corals and brachiopods in the limestone lenses and layers, as well as in pebbles of limestone conglomerates, at a number of places on the northeastern flank of the trough. According to M.A. Borisyak who was kind enough to look over the brachiopods, and to V.A. Sytova and O. Bondarenko who identified the corals, our collection included Favosites forbesi M.E. et H., Mesafavosites bonus. Sok., Favosites ex gr. hisingiri M.E. et H., Conchidium knighti Sow., C. pseudoknighti Tschern., Lissatrypa cf. kazakhstanikha Boris., Eospirifer sp. In addition, there were many unidentified crinoids, stromatopora, and bryozoa. Pelecypods are less common. A portion of these forms is typical of the Wenlock; another portion of the Ludlow stage of the Upper Silurian; therefore the age of these rocks is best assumed as Wenlock-Ludow.

Such is the character of the Upper Silurian red formation in the northwestern limp of this syncline.

Farther northwest, in the Kargabulak Springs Area, the limbs of this structure, made up of Upper Silurian sediments, are seen to close about its central part consisting of Devonian deposits. For this reason, the Upper Silurian is considered best developed here and, more important is of somewhat different facies again. Beside terrigenous deposits represented by the same sandstones, siltstones, and argillites, with chunks and boulders of limestones; the limestones themselves are well developed here in two large massifs on both sides of the spring (Fig. 1). One of them is 5 kilometers long and 800 meters to 1 kilometer wide; the other is more isometric (3 x 1.5 km). Both massifs are made up of reef limestones represented by two varieties: pink, mottled, locally brecciated, abundant in crinoid segments and rare large brachiopods; and by gray, massive limestones virtually made up of corals and stromatopora. V.A. Sytova, O. Bondarenko, and M.A. Borisyak identified here Entelophyllum prosperum (Barr.), Tryplasma sf. loweni M.E. et H., Brachyelasma sp., Neobrachyelasma g. n., Aseptiphyllum cargabulakum Syt. sp. nov., variant of Favosites forbesi var. nitidula Pocta, and numerous representatives of the genus Heliolites (gray limestones); among brachiopods, the dorsal valve of a large Conchidium knighti Sow. (pink limestones).

Most of these forms are known from the Ludlow Upper Silurian; however, the Triplasma loweni is known from the Wenlock and Ludlow of England, whereas the Aseptiphyllum cargabulacum occurs in the Kazakhstan lower Ludlow deposits (the Medina area). Consequently, the age of these rocks, as is the case for the area north of Akzhar-Sarytum structure, should be assumed as Wenlock-Ludlow.

It is clear from the above exposition that the upper red formation in the Kargabulak Springs area is essentially similar to that described from the preceding sections. The only difference is the growing importance of limestones which make up fairly large massifs, here, and attain thicknesses of 150 to 200 meters.

In conclusion, a few words on the petrographic features of Silurian rocks in the area under study. On the basis of V.V. Kopteva's study of thin sections, the following petrographic groups can be separated in the lower porphyrite formation ($S_1^a$):

1. Basalt porphyrites with incrustations of a plagioclase, usually strongly altered, but locally determined as labradorite No. 63, and of olivine.

2. Pyroxene-plagioclase porphyrites, subordinate to the basalt porphyrites. Their incrustations contain plagioclase corresponding to oligoclase No. 28 and pyroxene, usually strongly altered.

3. Biotitic andesite porphyrites, observed in thin intercalations among the basalt and pyroxene-plagioclase varieties.

4. Hornblende andesite porphyrites.

5. Tuffs and agglomeratic tuffs of andesite porphyries with fragments of plagioclase and dacite porphyrites.

6. Sandstones, occurring in subordinate layers in the top of the formation. Their clastic material contains much basalt and other porphyrites, similar to those described above.

Predominant in the overlying $S_1{}^b$ and $S^{w\text{-}ld}$ sedimentary sequence are clastic rocks. In the $S_1{}^b$ formation, they are chiefly tuffaceous sandstones with a large amount of acid pyroclastic fargments and a smaller amount of basic extrusives.

In contrast, arkosic sandstones are chiefly developed in the upper red formation — from fine and medium grained to gravelly. Besides the clearly predominating arkosic material, the fragments contain many rocks from underlying beds: andesite porphyries, sandstones, tuffaceous sandstones, also acid extrusives and ash tuffs from beds $S_1{}^a$ and $S_1{}^b$. Less common are metamorphic Cambrian sandstones, granites, quartzites, etc.

Volcanic formations, in subordinate intercalations in both the $S_1{}^b$ and the upper red formations, are represented by a series of dacite lavas and their pyroclasts, either in quartz or in quartzfree varieties. Tuffs are predominant, with the lavas themselves very scarce.

The following petrographic varieties may be separated here:

1. Plagioporphyries, represented chiefly by quartzfree varieties and consisting of andesine inclusions in a fine-grained, chiefly plagioclase groundmass.

2. Plagioporphyries tuffs, in all varieties from coarse grained to fine ash.

3. Tuffs of quartz plagioporphyries with coarse incrustations of quartz, altered plagioclase, and fragments of porphyries and porphyrites.

Having thus completed the description of Silurian deposits in the Kargabulak Springs area and the region southeast of there, we shall attempt a correlation of these formations with those in the Ak-Kerme Peninsula and in the vicinity of the settlement at Mynaral [1, 2].

These areas lie on the same strike, 70 to 75 kilometers from each other. Figure 2, presenting their respective stratigraphic columns, shows the most resemblance in their upper intervals. Indeed, the above-described upper red formation with limestones carrying a Wenlock-Ludlow fauna is readily correlative with the Akkan bed of B.M. Keller. According to him, that bed is represented not only as a limestone facies rich in fauna (the Akkan limestone) but in part as red beds. As it is in the Kargabulak area described above, here, too, the facies replace each other over short distances, commonly within the same fold ([1], page 8).

The similarity in the upper half of the two sections is further enhanced by the fact that the sequence with a Wenlock-Ludlow fauna — both in our area (the northeastern synclinal limb section) and in the Ak-Kerme Peninsula (south-western bayshore) — is overlain by red argillites and siltstones which evidently belong to the uppermost Ludlow beds. Thus the upper parts of the columns are fully correlative.

The situation is more complicated in the lower part of the section, represented by formations $S^a$ and $S^b$ in the Kargabulak Springs area; and the Llandovery ($S_1^{l1}$) formations and Tarannonian beds ($S_1{}^t$) — transitional from the Llandovery to Wenlock — in the Mynaral area.

According to B.M. Keller and his coauthors, the Tarannonian beds are marked by radical facies changes over short distances. For instance, on the Ak-Kerme Peninsula, they are represented by red-brown siltstones and siliceous argillites with a graptolite fauna; they are replaced in places (northeastern limb of the Ichkinsk syncline), in the area of the so-called Mynaral monoclinal block by volcanic formations, such as assorted andesite porphyrites, albitophyres, and porphyries with subordinate sedimentary beds carrying Tarannonian graptolites at the base of the section. However the overall thickness of the volcanic sequence in the Mynaral monoclinal block is so great (1,000 to 1,300, locally as much as 3,000 meters) that B.M. Keller and his collaborators believe it corresponds here not only to the Tarannonian but possibly to the entire Wenlock and Ludlow which are represented as limestone facies in the south.

The Llandovery formations are also changeable, by facies. In the Ortana anticline province, they attain considerable thickness (225 meters) and consist of conglomerates, tuffaceous-siliceous to siliceous shales with graptolites, and of sandstones and tuffaceous sandstones. In the Ak-Kerme Peninsula, the Llandovery stage is very closely related to the Tarannonian beds and is barely separable from the latter. It is represented here either by terrigenous rocks — conglomerates, sandstones, and siltstones, or else by limestones with an abundant coral fauna. Finally, B.M. Keller and his collaborators assign to the Llandovery a thick sequence of the so-called

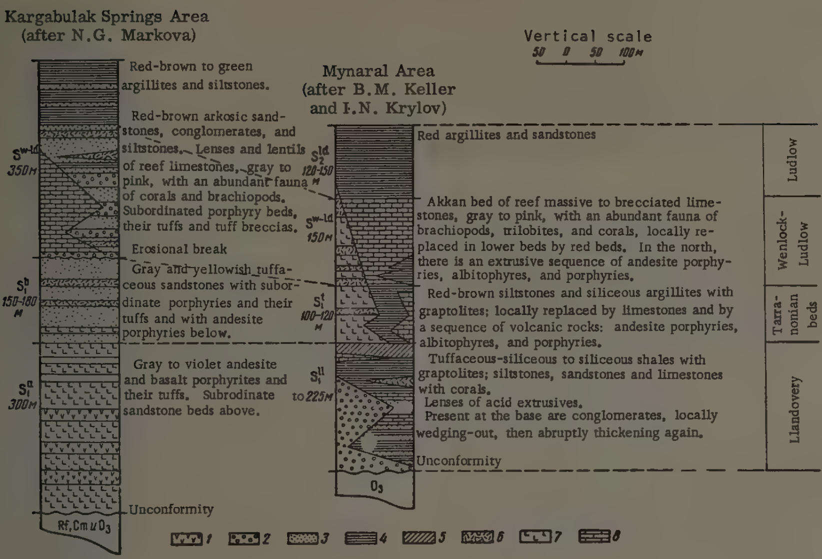


FIGURE 2. Correlation of Silurian sections of the Mynaral and Kargabulak areas.

1 -- Basalt porphyries and their tuffs; 2 -- conglomerates; 3 -- sandstones; 4 -- siltstones and argillites; 5 -- siliceous shales 6 -- albitophyres, porphyries, and their tuffs; 7 -- andesite porphyries and their tuffs; 8 -- limestones.

Mynaral conglomerates, first described under this name by A. Ye. Repkina (1944).

Thus the lower parts of stratigraphic columns in the Kargabulak Springs and the Mynaral areas do differ considerably in their lithology.

Nevertheless, there is the significant fact that in both instances the formations underlying those, carrying a Wenlock-Ludlow fauna, carry sequences connected by a gradual transition and having a like thickness. It is quite possible that they are facies of each other, i.e., the $S_1{}^b$ formation of the Kargabulak area should be assigned to the Tarannonian, whereas the lower $S_1{}^a$ to the Llandovery. Such an assumption is quite plausible, considering the abrupt facies changes which are peculiar to the Silurian as a whole and which have been noted by us and by other students. Specifially, an abrupt replacement of sedimentary formations by extrusives has been demonstrated by B.M. Keller and I.N. Krylov for the Tarannonian beds, and evidently for higher Silurian beds, as well. We only have to suppose that the Llandovery sediments, too, are subject to such replacements. It seems to us that the above-described material from the Kargabulak area lends substance to such an assumption.

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Geologic Institute,
Academy of Sciences, U.S.S.R.
Moscow

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# BRIEF COMMUNICATIONS[1]

## THE MOST RECENT TECTONIC MOVEMENTS AS REFLECTED IN THE STRUCTURE OF THE MIDDLE KAMA TERRACES[2]

by

B. S. Lunev

Recently, the study of geomorphology with the aim of discovering positive structures has, in various areas, been conducted on a large scale. Considerable work in revealing the relationship between relief and tectonics has been done in the Volga valley.

Manifestations of tectonic movements in the Kama region Quaternary have been noted by B.A. Aprodov [1], D.V. Borisovich [2], S.G. Kashtanov [5, 6], L.O. Rozanov [10], and V.N. Sementovskiy [12]. In 1956, G.A. Maksimovich read a paper on the relationship of relief and tectonics in the Permskaya Oblast' (Province), at a session of the All-Union Geographical Society, U.S.S.R.

L.A. Ragozin ([9], page 19) has established that "one or another type of the Quaternary mantle is always associated with a definite tectonic structure of the basement. Oftentimes, even a simple analysis of thickness of Quaternary deposits reveals their undisputable relationship with ancient structures." He has proposed a number of geomorphologic features in aid of the search for such structures; most of them are applicable in the Middle Kama region.

Well defined along the Kama (from the mouth of the Saygatka River to Solikamsk), there is a flood plain, four above-flood terraces, and a high plain. The flood plain is usually adjacent to the first terrace. Participating in its build-up are three distinct lithologic beds: gravel-sand at the base (channel facies); and clay-loam at top (flood facies). The thickness of these beds changes in a wide range, depending on the hydrographic network and the geology of the original rocks.

Two of these beds are best expressed in the structure of the first above-flood terrace: a sandy-gravel at the base and a sandy one on top. Large lenses of clays and loams occur locally between them. Near the outer edges of the terraces, there are widely developed alluvial mantles of great thicknesses, represented chiefly by loams and clays. The second above-flood terrace has a foundation of gravel-sands at the bottom and sands above them. Loams and clays, either overlying the sands or included in them, are not always present. The third and fourth terraces also have foundations usually of sand-gravel deposits at the bottom, with loams and clays above them. In the third terrace, sands of the middle beds or loams and clays of the upper bed also are missing, locally.

At the present time, since the Kamsk Hydroelectric Station (G.E.S.) has been built, a considerable area in this region has been flooded and some of the terraces are under water. Given below are elevations for the terraces bases above the fairway, before flooding. As a result of our field work and study of all available literature (Yu.A. Razumovskiy, 1948; P.A. Sofronitskiy, 1955; G.I. Goretskiy, 1950, 1945; etc.), we have come to the following conclusions on the relationship of the terrace build-up and the structures developed chiefly in Upper Permian deposits.

1. The smallest thickness of Quaternary alluvium has been observed in the area of development of positive structures. The granulometric composition of gravel-sand deposition is a function of recent tectonic movements.

At the Kama mouth, near Krasnokamsk, there is an appreciable erosion of alluvium and of original rocks. Inasmuch as there is a positive structure present here, with an accompanying meandering of the river, the erosion has undoubtedly resulted from an uplift of the dome on one hand, and by local transversal circulation of the water stream. Higher upstream, at the village of Proletarskoye, on a straight stretch of the Kama, where the transversal circulation is less intensive and where there is no uplift, a considerable

[1] Melkiye soobshcheniya.

[2] Otrazheniye noveyshikh tektonicheskikh dvizheniy v stroyenii terras srednego prikam'ya.

thickness (about 6 meters) of coarse-clastic alluvium was found in the Kama channel. Somewhat south of the center of the Polazensk uplift, along a straight stretch of the river where the transversal circulation is poor but where the doming effect is still perceptible, the coarse-clastic alluvium in the Kama channel is thin, locally missing altogether.

Throughout the Kama region, the gravel content in alluvium (channel facies) decreases from east to west — from the source to the mouth [8]. However, the amount of gravel in a sand-gravel mixture increases over upwarpings. Thus at the village of Dobryanka, where the doming is poorly expressed, gravel is either lacking in the flood-plain alluvium or else is present in very small amounts; on the other hand, at the village of Zalesnaya, where the uplift is more pronounced the alluvium carries more gravel. This relationship is even more pronounced in the area of Krasnokamsk and Zakamsk. A small syncline in Upper Permian deposits occurs between these two towns, which includes a portion of the Zakamsk gravel pit. The average gravel content here (150 + 5 millimeter fraction) is 45 per cent. Farther upstream, at Zakamsk, in the Zelenikhinsk gravel pit, and farther down the Kama, at Krasnokamsk, in the Kachkinsk pit — both associated with anticlinal crests — the gravel content is 61.26 per cent in both instances. On the south limb of the Krasnokamsk uplift, within the gravel pits at Vyatskiy Ostrov and Novo-Il'insk inlet, the gravel content is reduced to 50%; it is 40% in the Zhmelevka pit on the Nytvensk bend, beyond the Krasnokamsk-Polaznensk swell. Up the Kama from Zakamsk, between the Krasnokamsk-Polaznansk and Lobanovsk swells, on the Kur'insk and Fominsk sandbanks, as well as in the Proletarskiy deposit, the gravel content is a little more than 40%. In the Gayvinsk gravel pit, associted with the southeastern limb of the Krasnokamsk-Polaznensk swell, the content of fraction 150 + 7 mm is 50.8%. In the Ust'-Chusovaya deposit, at the junction of the Krasnokamsk-Polaznensk and Lobanovsk swell, the content of fraction 150 + 7 mm is 42.6%. Near Gayvinsk Island, the Kama has washed out the alluvium in its channel and is flowing over bedrock, whereas it flows over a comparatively thick alluvium near the mouth of the Chusovaya River (Ostrov Village), because of a subsidence in relief. The relationship between the granulometric content of alluvium and neotectonics has also been noted by L.A. Ragozin ([9], p. 19).

The first above-flood terrace of the Kama has the following thicknesses of alluvium in areas of positive structures: Borovsk, 18 meters; villages of Demidkovo, Ust'-Polazna, Gamy (by Krasnokamsk), 20 meters. Different thicknesses of alluvium have been observed in areas of negative structures: 3 to 4 kilometers south of the village of Zmeyevka (Berezniki area), at the northern limb of a syncline, it is 23 meters, with 30 meters at the center of that fold, at the mouth of the Syn'va River; it is 25 meters on the south limb of a syncline between the Durnitsa and Norka Rivers; and 28 meters at the noticeably plunging limb of an anticline.

2. The bedrock base of terraces rises toward crests of positive structures.

Within the Kama flood plain and its first above-flood terrace, the rise of bedrocks toward the Krasnokamsk-Polaznensk swell, in the area of the Nytvensk bend, is more than 4 meters. Between the Nytva River and the town of Okhansk, where the Kama twice crosses the end of the Krasnokamsk-Polaznensk swell, thus defining the uplift, the rise of bedrock from the Kama channel to the swell axis is 8 meters. In the Krasnokamsk area, the rise of bedrock toward the uplift is 6 to 7 meters, along the left bank of the Kama, and about 9 meters along its right bank.

In troughs, the elevation of the bedrock foundation of the first above-flood terraces above the water edge is as follows: at the village of Novinki (Berezniki area), 1 meter; settlement of Pozhva, 3 meters; at the villages of Gorevskaya and Kitayevka, going toward the Polaznensk positive structure, it attains 6 meters; on the left bank of the Kama, between the Lenva River and the village of Chashkino, in a syncline, it is 3 meters, whereas on an anticline at Zayach'ya Gorka, nearby, it is 5 meters; at the village of Orel, on the south anticlinal limb, it is 9.5 meters. In the Orel area, the rise of the second above-flood terrace base toward the crest of an anticlinal fold near Usol'ye is more than 3 meters. In the area of the Lys' and Lenva Rivers, the terrace base is 5 to 6 meters above the water edge; it attains 11 meters with approach to the northern limb of the Polaznensk uplift.

Vertical electric logging was done at two points near Usol'ye (VEZ-104, 3 kilometers west of Kama, and VEZ-107, 4.5 km west of it), to determine the alluvium thickness and the position of bedrock under the second terrace. Here, the thickness of Quaternary deposits increases from 15 to 20 meters toward the outer edge. The bedrock rises 5 meters toward the uplift center (toward the Kama channel), which undoubtedly was formed by recent tectonic movements, as has been the decrease in the alluvial thickness in the same direction.

In the third above-flood terrace, at the left bank of the Kama, from the Oshva River toward the Krasnokamsk-Polaznensk swell, the bedrock rises 7 meters (from 22 to 29 meters above water edge); at the village of Kamen'

near Usol'ye, in the crest of an anticline, the bedrock elevation above the water edge is 28 meters, whereas it is 12 meters in a syncline, 8 kilometers south of the Pozhva mouth; in the area of the Pozhva and Yemel'yanikha Rivers, on a synclinal limb, the bedrock is 15 to 20 meters high, whereas it stands 25 meters above the water edge at the Kos'va mouth, near the Polaznensk uplift. At the village of Dvortsovaya Sludka, the bedrock rises 5 meters toward the Krasnokamsk positive structure; at the village of Saygatka, the rise is more than 10 meters, toward a positive structive 10 kilometers east of Votkinsk. The rise of bedrock in the fourth above-flood terrace toward the Lobanovsk structure is 13 meters.

3. In crossing anticlines, the Kama valley narrows, in crossing synclines and monoclines, it grows wider.

Appreciable widening of the Kama is present in the village of Gayna area, between the Berezniki and Dobryanka Villages, and in a number of other places. An abrupt narrowing of the valley is present in the Polazny Village area and between the towns of Osa and Chastyye. Within the Polaznensk uplift there is some widening in the valley where it flows over outcrops of gypsum and anhydrite; this is due to a greater solubility of the latter as compared with other rocks of the area. The width of the valley is also affected, to a certain extent, by the Kama tributaries. The dual crossing by the Kama of an anticlinal axis, represented by terrigenous deposits in its crest, has led to a widening of the valley (towns of Krasnokamsk, Nytva).

4. The Kama crossing of positive structures is commonly reflected in a sharp bend of the valley (village of Polazny, towns of Osa, Chastyye, and others).

Other than the clearly expressed relationship of positive and negative structures with the shape of the valley, the alluvium thickness, etc., it is very difficult, in a number of places, to determine the tectonics of an area from the shape of the valley and the structure of terraces. This difficulty arises from many causes: 1) near-channel levies, which originate from a transversal flow of water may increase the alluvium thickness over uplifts; 2) a similarity in the lithologic composition of alluvium, widely developed near the outer edge of terraces in many places, complicates the determination of the thickness of river deposits; 3) intensive erosion, brought about by transverse flow, may appreciably lower the terrace base in the area of an uplift; 4) the width of a valley depends, to a considerable extent, on the lithology of the bedrock. In the process of erosion, carbonate rocks are more resistant than quartz-feldspar sandstones and "Vapa-rock" [3, 4, 11, 13]. Salt structures in the area of Solikamsk and Berezniki also appear to have a definite effect on the formation of relief. In the opinion of G.I. Goretskiy, the formation of a Tertiary and Eopleistocene ancestral Kama (Prakama) is related to the salt tectonics of the area. On the other hand, the presence of an Eopleistocene ancestral Kama in the Perm area, as noted by Yu.V. Razumovskiy, and at the Kama mouth, as noted by S.G. Kashtanov [6] — with salt tectonics absent in both places — proves the effect of neotectonics on present relief.

A solution of the neotectonic problems is further complicated by the fact that this region lies in a transition zone, as far as the surface mantle age and the age of structural activity are concerned [7].

The presence of recent tectonic movements in this area is suggested by periodic earthquakes, with an intensity of 4 to 7 points [14, 15].

It is possible to infer neotectonic movements in the middle Kama region from the morphology of its valley and from the terrace structure. However, a number of other factors should be taken into consideration: 1) the effect of the Kama bends and of the lithology of bedrock on the shape of the valley and the structure of terraces; 2) whether the river crosses rocks along their strike, with the dip, or against it; 3) the flow rate and the flood run-off; 4) local backing up of tributary waters by spring floods, etc.

Thus, the nature of terraces and leveled-off surfaces is inconsistent throughout the middle Kama region, the inconsistency being due to differential tectonic movements. Their erosion-deposition sequence suggests oscillatory vertical movements during the Quaternary — both regional, throughout the middle Kama, and local, in the areas of development of positive and negative structures.

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The A.M. Gor'kiy University
Perm

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## EXPERIMENTAL DATA ON PLASTIC DEFORMATIONS IN QUARTZITE

by

I.S. Delitsin and Yu.A. Rozanov

The study of D. Griggs and J. Bell [5] has shown that brittle deformation alone is typical of quartz, under conditions of a high confining pressure (within the experimental range). Later on, P. Bridzhmen [1] confirmed this in a series of experiments. In these experiments,

[3] Eksperimental'nyye dannyye po polucheniyu plasticheskoy deformatsii v kvartsite.

as in those by D. Griggs and J. Bell, the strength of quartz grew linearly with hydrostatic pressure (the maximum value of quartz strength in compression was 40,000 kg/cm$^2$ for hydrostatic pressure of 25,200 kg/cm$^2$). In all the experiments by Bridzhmen, a complete collapse of the samples took place, with quartz turning to fine powder without any evidence of plastic deformation.

On the other hand, experiments of Ye.V. Tsinzerling and A.V. Shubnikov [4] have shown that plastic deformation of quartz can be obtained at high temperatures, near the point of transition of low-temperature quartz to high-temperature quartz (under conditions of a directed pressure as much as 1,000 kg/cm$^2$). It is true that deformation was merely expressed in Dauphin twinning, without any visible shifting of parts of a sample with relation to the others, or of shortening of the sample, or of any other evidence of deformation. However, the very fact of twinning establishes, convincingly enough, the initiation of plastic deformation.

Field observations of I.S. Delitsin in the area of development of quartzite-marble sequences in the southeastern Baltic region have shown that the phenomenon of plastic deformation in quartzite has a wide regional development and is manifested in the differentiation of the more brittle marble intercalations into lenses, by the quartzite. The thickness of such lenticularly split layers of quartzite-marble carbonate sequences attains 400 meters, over distances of tens of kilometers. A microscopic study of these rocks (specifically of the mineral associations) has established that the formation of such split ("Boudinage") structures could have occurred at great depths, in the presence of solutions and with appropriate, thorough heating of the entire rock body [2].

Experimental studies were set up with consideration given to these observations and to the experience of Soviet and foreign students.

For the purposes of experiments, cylindrical samples of quartzite were prepared, with a diameter of about 15 centimeters and 24 to 26 centimeters long. These samples were deformed in cylindrical steel forms. Turned forms were used, with walls thinner in their middle part. The pressure was applied to a sample by a hydraulic press (with as much as 300 metric tons capacity) by means of two pistons confining the sample in its form. A deformation of the sample could take place only with deformation of the walls. According to Yu.A. Rozanov and others [3], the wall deformation occurred in a weak part where thickness was only 2.5 millimeters., at approximately 12,000 kilograms pressure on the pistons, or about 6,800 kg/cm$^2$ (the area of the piston and the sample was 1.75 cm$^2$). The system was heated by means of a Nichrome spiral insulated by asbestos. The current was supplied directly, without a rheostat, from a reducing transformer producing 6 and 8 volts, which insured a temperature of 160 and 200°C, respectively. The temperature was measured by a thermocouple, on a standard sample.

As in the Griggs-Bell experiments, we used alkali solutions for the medium: the sample was soaked in soda solution for seven days.

A sample was emplaced in its container by a method worked out by Yu.A. Rozanov [3], which made it possible to experiment with water-saturated samples and provided for tight packing.

The experiments were carried out with strongly deformed quartzite, marked by a definite orientation of its component grains (porosity of quartzite, about 0.8%). The original quartzite was represented by strongly elongated quartz grains to as much as 3 x 1 millimeters. The grain edges were serrate and interlocking. New formations of a fine-grained quartz at grain junctions were usually present in more deformed segments. The quartz grains were marked by a cloudy, wavy, less commonly by a banded extinction, and by the virtual lack of Boehm's bands (very poorly expressed). Very rare fine fractures (as much as 1 millimeter long) were usually developed within a single grain, in various directions. Diopside grains in quartzite, as much as 0.8 millimeter, were rounded or else somewhat elongated; their accumulations were usually oriented with the quartzite banding.

This is well illustrated in Figure 1, in the somewhat uneven enveloping of a thin tabular accumulation of diopside by light-gray quartzite with isolated diopside grains (white in picture). The high degree of deformation in the original quartzite is confirmed by the results of petrofabric analysis. Two series of measurements (across the banding) were performed in the upper and lower parts of a sample (50 measurements of optical axes of quartz in each band).

A diagram of the upper series of measurements (Fig. 2A) is on the whole not different from that of the lower zone (Fig. 2B). This similarity of the two diagrams suggests that the pattern in a given plane, despite a few specific deviations, is permanent for the quartzite in a given sample.

After being saturated, the cylindrical sample was subjected to an overall pressure of 14,700 kilograms (directed pressure, 1,600 kg/cm$^2$). The maximum heating temperature

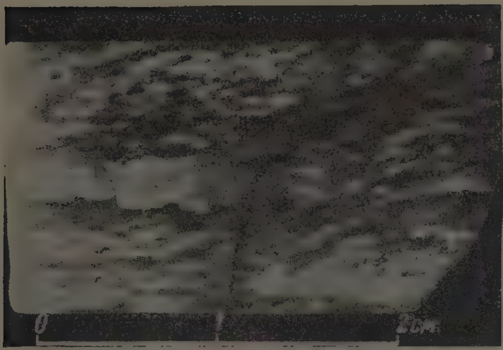


FIGURE 1. Polished section of the original quartzite.

Gray -- quartzite; white -- diopside.

was as much as 200°C. The duration of heating at 160°C was 30 minutes; at 200°C, 5 to 7 minutes. The experiment lasted one hour, 48 minutes.

Upon removal from the container, the sample did not collapse, so that it was possible to prepare a thin and a polished section in a plane perpendicular to its banding. A postdeformation measurement of the sample showed a certain decrease in its height: 25.2 millimeters against 25.5 mm before deformation, i.e., a shortening of 0.3 mm. Attempts to measure the postexperimental diameter of the sample were unsuccessful.

The thin section (Fig. 3) shows a change in the color of quartzite: after the experiment, the quartz grains became lighter colored and more transparent than in the original quartz, whose relicts were preserved at the base of cones adhering to the pistons. These

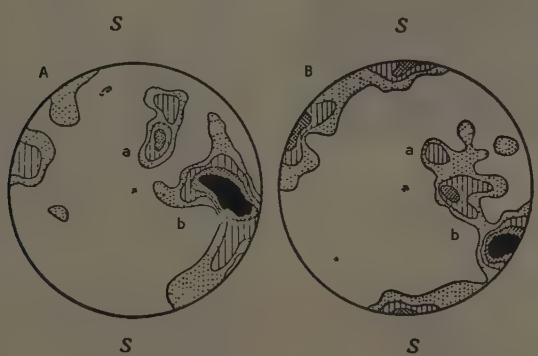


FIGURE 2. Two series of measurements in the upper (A) and lower (B) parts in a sample of the Figure 1 type, showing a fiarly similar optical orientation of quartz grains in quartzite.

S is the direction of banding in the sample. Each of diagrams A and B have been constructed from measurement of 50 optical axes of quartz; isolines: 2—4—6—8—>%; max = 10%; a, b -- typical maxima of diagrams.

cones were shifted somewhat with relation to the sample axis, in opposite directions; this is explained by the nature of banding in the given segment, as well as by a slant in the pistons.

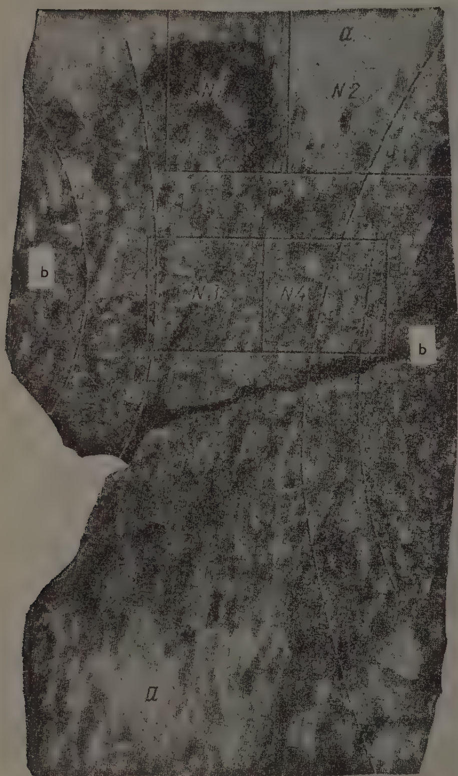


FIGURE 3. Quartzite after deformation.

a -- "Cones" adjacent to pistons; b -- zones of deformation; numbers designate the measurement areas illustrated by petrofabric diagrams (Fig. 4).

Polished section. Magnification 6X.

The plastic deformation which has taken place here is graphically illustrated by the bending of elongated quartz grains in the deformation zones (shown by dashed lines in Fig. 3). These zones are marked by arching of the grains.

The microscope shows that the bases of the cones are made up of an original type quartzite, described above. A thin zone above the cones exhibits a certain increase in the grain size, 1.5 to 2 times.

The grain outlines become smoother, without the distinct serrate interlocking edges and without the new formation of a fine-grained quartz; this probably suggests the possibility of a recrystallization in these segments. The peripheral zones of deformation exhibit a change in the grain size: they are smaller (as much as one millimeter) and more elongated; their width-length ratio is 1:2 to 1:6 (mostly 1:2 to 1:3). Fine-grained quartz material has been observed between the grains. The curvature of individual grains in the deformation zone usually is small; however, on the whole, it creates the effect of plastic deformation which is quite conspicuous in polished section. Despite the curvature in the quartz grains, the nature of their extinction is only locally more distinct than in the original quartz grains.

Like the quartz grains, the diopside grains in the cone zones adjacent to the pistons, did not undergo additional deformation. Diopside grains in the deformation zone of the sample exhibit wide twinning bands; locally, the diopside grains are somewhat elongated and oriented in the direction of the quartz grains curvature.

Unfortunately, the sharp primary orientation of quartzite renders the picture of the subsequent deformation less convincing. The development of fracturing is of interest, with fractures observed in all three directions (the gaping transversal fracture in Fig. 3 is a break after the preparation). Longitudinal and transversal fractures are thin and in few places cut more than 2 or 3 quartz grains; diagonal fractures predominate, although of a single system. Three such fractures have been observed in the polished section (forming an angle of about 35° with the direction of force), but none cuts the entire sample. Plumate fractures are rare. The number of fractures of all systems is reduced sharply in zones adjacent to the pistons.

The Wood's alloy, used in sealing the sample, is distributed in the fractures in grains and not between the grains.

Considering the appearance of curvature in quartz grains and of a more distinct extinction in them, along with the appearance of twins in diopside and with the considerable amount of fracturing in the quartz grains, it is fairly certain that plastic deformation was initiated somewhat earlier than the brittle; at later experimental stages, the two appear to have been developed simultaneously.

A thin section of the deformed sample was studied by the petrofabric analysis method. Diagrams were constructed for individual segments of the thin sections. The areas of corresponding measurements are marked on polished section, Figure 3. Petrofabric analysis data are given in Figure 4. We shall consider them in more detail.

Area 2 (Fig. 3). The diagram of this area shows the orientation of quartz grains in quartzite at the base of the cone adjacent to the piston. It is readily seen that maxima a and b may correspond to those in the original quartzite diagram (Fig. 2).

Area 1. The diagram of orientation of the quartz optical axis shows the development of a single well-defined maximum, probably marking a deformation zone of this area. The presence of a high concentration of densities in this maximum (as much as 26%) confirms the possibility of orientation of quartz in that zone.

Area 3 lies outside the cone zone in contact with the piston. It is marked by the same direction of banding as in the cone zone (area 2). Its diagram shows a process of reorientation. Maxima a and b in diagram 2 of this area are found here very close together, with an intensive development of the upper maximum alone, where density approaches 22 per cent.

Area 4 lies below 2 and represents a part of the right hand deformation zone. This area is marked by a very sharp reorientation.

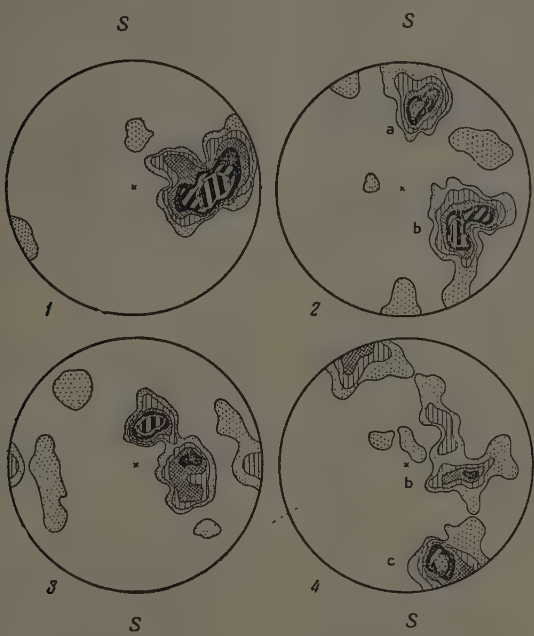


FIGURE 4. Optical orientation of quartzite grains in individual segments of deformed quartzite.

Each diagram has been constructed from 50 measurements of optical axes of quartz; the diagram number corresponds to a measurement area of polished section Figure 3;
a, b, c -- typical maxima of a diagram.
S is the general direction of banding in a specimen.

Diagram 1; isolines 2--4--6--8--10--12--14-- > %; max = 26%
" 2; " 2--4--6--8--10--12--14-- > %; max = 18%
" 3; " 2--4--6--8--10--12--14-- > %; max = 22%
" 4; " 2--4--6--8--10--12-- > %; max = 14%

The characteristic maximum a in diagram 2 is not expressed here at all. The more conspicuous maximum b in diagram 2 (max = 18%) is rather poorly expressed in diagram 4 (max = 8%). However, in contrast to diagram 2, a new maximum c (max = 14%) is developed in diagram 4. Thus petrofabric analysis confirms the macro- and microscopic data on the deformation which has taken place. Repeated experiments under the same conditions gave similar results.

The data cited are sufficiently convincing that in this experiment there were initial stages of plastic deformation in quartzite. The experimental results are far from perfect; still, they suggest the possibility of obtaining plastic deformation in quartzite and quartz, under conditions which generally approach the natural (pressure, temperature, solutions).

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Institute of the Geology of Ore Deposits,
Petrography, Mineralogy, and Geochemistry
Academy of Sciences, U.S.S.R.
Moscow

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# REVIEWS AND DISCUSSIONS[1]

## B.B. RODENDORF'S BOOK, "PALEOENTOMOLOGICAL RESEARCH IN THE U.S.S.R.[2,3]

by

Yu.M. Zalesskiy

This work is a review of the study of fossil insects of this country; it is dedicated to the noted Russian paleoentomologist Andrey Vasil'yevich Martynov. The book consists of a foreword, introduction, and six parts: I — "Works of A.V. Martynov, 1921-1938;" II — "The Development of Paleoentomology in the U.S.S.R., After A.V. Martynov;" III — "The Prospects of Future Study;' IV — "List of Fossil Insect Sites in the U.S.S.R.;" V — "List of Fossil Insect Species of the U.S.S.R.;" VI — "Literature on Fossil Insects of the U.S.S.R."

As stated in the foreword, the author's purpose is to summarize what has been done in the U.S.S.R., in the field of paleoentomology, first of all from the work of A.V. Martynov who was first to specialize in the study of fossil insects of this country and to lay the foundation for this branch of paleontology in the U.S.S.R.

After a brief review of the status of paleoentomological study prior to A.V. Martynov, the author notes that Russian paleoentomology, at that time was practically nonexistent. He further states that "because of special features of the method of study of insects in amber, and of the latter's very small significance in biostratigraphy," a consideration of amber insect fauna is omitted. Such an omission has little justification, and it is regrettable that the results of the study of more than 3,000 species are missing in this review.

Paleoentomology — this young branch of paleontology — is little known among both entomologists and geologists, and an acquaintance with the achievements and promises of this discipline is very important for its development. A publication of such a review is welcome. Unfortunately, this exposition of the development of paleoentomology contains inaccuracies, a nonobjective exposition of some facts, and an underestimation and disregard of some others.

The author sets the beginning of A.V. Martynov's activity in the field of paleontomology as 1925, when that scientist published his first seven works on fossil insects. It is stated that in his first papers (evidently in 1925, because the author next mentions the year 1926), A.V. Martynov pointed out the importance of fossil insects in the determination of geologic age. However, these works, being purely descriptive, could not have revealed any such importance of fossil insects in stratigraphy, which assertion should have been relegated to A.V. Martynov's later works. Contrary to the author's assertions, the attention of field workers has not been attracted to this subject. The majority of them are still in the dark as to the stratigraphic significance of insects.

In the chapter on "Study of Faunal Assemblages," which tells of A.V. Martynov's work on individual faunas, on page 10 (line 26 from top) reference is made to the Kargala and Chekarda faunas in the plural, whereas, in fact, the described Kargala forms represent a single fauna, and the Chekarda fauna is not an independent one but is rather the component of a large and widely distributed fauna of the Kungarian Tis formation known from the Sylva basin.

Writing on A.V. Martynov's work in phylogeny and systematics, the author reads in them more than they contain and does not give enough attention to what they actually do

[1]Kritika i diskussii.

[2]O knige B. B. Rodendorfa "Paleoentomologicheskiye issledovaniya v SSSR".

[3]Trudy Paleontol. Inst., t. 66. Izd. Akad. Nauk SSSR, 1957, 101 pp. (with illustrations).

contain. For instance, it is stated on page 11 (lines 9-12 from the bottom), "Martynov has convincingly demonstrated that from an aerodynamical point of view, the wings of ancient Paleodictyoptera were well suited for strong strokes." It is well known that A.V. Martynov was not engaged in the aerodynamics of insects, let alone fossil insects. He drew attention to a primitive state of roaches' upper wings as compared with those of Paleodictyoptera, which is related to the function of those upper wings as a sheath. According to A.V. Martynov, the upper wings of roaches are closer to the primitive wings of the ancestors of the entire insect class.

The author points out (p. 11) that A.V. Martynov, working as he was with very diversified material, was unable to carry on a systematic paleoentomological research. A.V. Martynov can hardly be accused of a complete lack of systematization in his work after he has given, in a comparatively short period, a description of numerous and diversified faunas, and has prepared on this basis a summary on the phylogeny and systematics of fossil insects; the first part is already published.

Mentioning only A.V. Martynov's description of some peculiar Orthoptera Glosselitrods and Caloneurods, and his establishing of the order of Myomoptera and other groups (p. 15), the significance of his work is belittled. A general reference at the end of a paragraph, to the effect that "All these new data forced a reexamination of the current ideas on the course of the phylogenic development of Orthoptera," together with a reference to the general works of A.V. Martynov, do not correct this shortcoming, so long as the reader is informed only about the existence of these works without establishing their real significance. Such treatment of a number of outstanding works of this scientist is hardly proper in a review whose avowed purpose is "to summarize to some extent what has been accomplished," (see Foreword, p. 3).

In the chapter on "Other Paleoentomological Studies," referring to works contemporaneous with A.V. Martynov's, the author, having mentioned the paleoentomological works of the paleobotanist M.D. Zalesskiy, states that the first works of Yu.M. Zalesskiy were published in 1932. However, in the appended bibliography, the first works of this author are dated 1931 (p. 94); they deal with insects in Permian deposits of the Kama basin and not with "certain insects from the Sylva River basin Kungurian fauna," as stated by B.B. Rodendorf; the 1932 work deals with the venation of Odonata and Ephemeridae, and with their phylogeny. Incidentally, all the early works of Yu.M. Zalesskiy, from 1931 to and including 1935, describe the Tikhiye Gory insects along the Kama, Kargala, and Kuznetsk, rather than the Kungurian insects of the Sylva River.

Also mentioned are works on Jurassic and Tertiary insects, specifically the noted monograph of the outstanding entomologist N.Ya. Kuznetsov on Lepidoptera in amber; very briefly mentioned are the individual papers of A.A. Shtakel'berg, T.I. Shchegoleva-Barovskaya, V.V. Popov, and of B.B. Rodendorf himself. The N.Ya. Kuznetsov monograph is discussed in somewhat greater detail, in page 41 of "Phylogenetic Studies;" however, his paleoentomology work is treated altogether too sketchily, although it was he who tried to provide ideological leadership in Russian paleontomology after A.V. Martynov's death, and to lead it along a more rational path charted by A.V. Martynov himself, long before B.B. Rodendorf.

In 1939, at the initiative of N.Ya. Kuznetsov, a joint meeting was held by The Paleontological and Entomological Societies, on the subject of paleoentomology. N.Ya. Kuznetsov was well aware that the development of paleoentomology should proceed at the same rate in the study of systematics of individual groups and of their development in time, as well as in the study of faunal complexes and individual assemblages (successfully accomplished by A.V. Martynov), for their subsequent use by geologists and paleontologists in their stratigraphic work. Thanks to N.Ya. Kuznetsov's efforts, a joint resolution on this subject was adopted by the two societies [1].

It is strange that nothing is said of A.A. Rikhter's works, although they are listed in the bibliography, inasmuch as one of the papers was inspired by A.V. Martynov and was completed under his direction while A.A. Rikhter was a Fellow at the Zoological Institute, Academy of Sciences, U.S.S.R.

In the "Conclusions", only the works of A.V. Martynov are summarized. For this reason they should have been placed before the chapter on "Other Paleoentomological Research."

In the beginning of Part II, "The Development of Paleoentomology in the U.S.S.R. after A.V. Martynov's work," the author indicates the three directions of paleoentomological study, which he discusses in three corresponding chapters, "A study of Faunal Assemblages For Individual Regions and Localities," "Monographic Study of the History of Individual Insect Groups," and "A Study of Patterns in the Historical Development of Insects."

In the chapter, "A Study of Faunal Assemblages," the true study of assemblages of a region or of an age is confused with the

carrying out of field work there, i.e., with the collection of material and the description of individual fossil insect groups. For instance, it is stated in page 28 that prior to 1949, only isolated findings were known from the Kuznetsk basin, whereas 27 localities are known there now, with the faunal characteristics of some of them based on the study of large collections consisting of many hundreds of remains." An impression is given that all these hundreds of remains have been analysed as to their "faunal characteristics," whereas, as a matter of fact, only a portion of these faunas has been analysed, i.e., isolated groups only, with their evaluation only as an overall summary. Again, we read, "In 1949, the Paleontological Institute, Academy of Sciences, U.S.S.R. began a study of this fauna (the Kuzbas fauna is meant; Yu. Z.), by initiating extensive field work of inspecting the previously known fossil sites, collecting fossils, and especially of looking for new fossil sites by a systematic study of sections of some definite formations. *Up to then, such an 'active' method of paleoentomological study had not been applied.*" (Italics mine; Yu.Z.). Such a statement is astonishing. This method, standard with paleontologist-stratigraphers, was used by M.D. Zalesskiy in his joint paleobotanical-paleoentomological expeditions (1934-1939) and by Yu.M. Zalesskiy in expeditions sponsored by the Moscow University (1938-1939) and by the Moscow Geological Exploration Institute (1946-1947). In the 1947 expedition of Yu.M. Zalesskiy, this "active" method was especially widely used over an area from the Kolva basin in the north to the Sylva basin in the south, and in a part of the basin of the Chusovaya River and its tributaries. The results of that investigation were published in individual papers (1950, 1951, 1956, 1957) as the first stratigraphic achievements by means of fossil insects.

With regard to present data on fossil faunas of the U. S. S. R., the author names, on page 32, the 50 known fossil sites of Tertiary insects; in a table, page 33, only 47 are listed. Such inaccuracy is very vexing.

In the chapter on "Studies of Historical Development of Individual Groups," we read, "Where A.V. Martynov, in his time, had to pay main attention to faunal research and to the describing of entire faunas, the situation is different, now, when the emphasis is on the study of individual systematic groups and phylogenetic branches." The fact is, that A.V. Martynov did not "have to" do that but wanted to do that and gave priority to the description of faunas. It is regrettable that "the situation has changed" in the Paleontological Institute, after his death. This perhaps has "raised the quality of systematic research," as the author notes, but it also has postponed the obtaining of results valuable for stratigraphic purposes — the objective which the author himself has been supporting. A.V. Martynov pursued the same goal, but he realized that conclusions reached without a comprehensive study of faunas sometimes lead to errors.

In the chapter on "Morphological Study," the author first of all mentions his study of the flight apparatus of insects. We cannot go here into an evaluation and criticism of these works, except for pointing out that his reference (page 35) to the importance of the 1951 conclusions [2] is utterly unfounded. The author wrties, "Such contradictory needs of Diptera, which determined the formation of their locomotion organs, were the speed in running and the clinging capacity of their legs, combined with the need of a fast take-off (high-lifting power) and of long-distance flight (strong pull)." The fact is that the magnitude of pull has no relation to the flight distance; nor is there any inconsistency between the speed of run and the clinging capacity of legs or between the speed of take-off and the capacity for long-distance flight.

Undeservedly little attention is paid to the results and conclusions of Ye.E. Bekker-Migdasova on the body morphology of proboscis Isoptera. Her works, both in morphology and systematics, mentioned by the author in the chapter on "Phylogenetic Study," are of much interest and undoubtedly deserve more attention. The work of N.Ya. Kuznetsov is reviewed in the same chapter — too briefly, as has been pointed out.

With regard to Yu.M. Zalesskiy's work on Permian insects of the Urals, the author says (page 42): "Zalesskiy did not carry out special research in the systematics and phylogeny of individual groups or else touched upon this subject very briefly, and that for groups of no great importance (for instance Embias); for this reason, his faunal and phylogenetic study of Permian insects in the Urals is not reviewed here." From a list of Yu.M. Zalesskiy's works, appended at the end of the book, it appears that problems of phylogeny and evolution are indicated by the titles of six papers, some of them definitely special studies in systematics and phylogeny.

The chapter on "Knowledge of Fossil Insects in Determining the Age of Deposits Containing Their Remains" gives general considerations on the significance of fossil insects in biostratigraphy, without citing any instances of their use for this purpose or for the age determination. To be sure, such instances are few, but still some of them could have been cited.

Part III — "The Prospects of Future Study" —

is satisfactory on the whole. However, the isolation of little known faunas is not quite correct because all faunas, including those known from fully or partly processed collections, are far from having been adequately studied.

Part IV comprises a list of insect fossil sites in the U.S.S.R., compiled by O.M. Martynova. It is very valuable, although some of its information is not quite correct, in places completely erroneous. For instance:

(Location) 17. Vishera I...The Solikamsk region. Should be Cherdynsk region.

18. Vishera II and III...(some distance above the village of Sartakovo exposure). should read, "some distance below").

189. Koshelevka. Permskaya Oblast' (Province). On the Koshelevka River, a tributary of the Ai River (basin of the Ufa River). As a matter of fact the site is in Bashkiriya; the Koshelevka is a tributary of the Ay River and not Ai.

I am omitting the wrong references to V.V. Pogorevich's collections from the Vorkuta formation [7, 8, 9, 10], which have been corrected by the author himself. Very valuable are the references to the literature describing the insects from these localities.

Part V contains a list of fossil insect species found throughout the U.S.S.R., compiled by Ye.E. Bekker-Migdasova, O.M. Martynova, A.G. Sharonov, and B.B. Rodendorf. Very conveniently, the list gives the age and the numerical order of a locality where a given species has been found; unfortunately, there is no reference to the work describing this species, although it could have been easily done by indicating the publication year and the index number.

Part VI — "Literature on Fossil Insects of the U.S.S.R." — gives a list of paleontomological works, with the exception of those dealing with the Baltic amber insects (for which only the N.Ya. Kuznetsov work is cited). Despite a few small bibliographical mistakes, this list unquestionably is very valuable.

The book carries evidence of hurry; this is a probable explanation of the many shortcomings and errors mentioned above, and of some not quite felicitous expressions, such as "stroke organs" (page 29) and "faunal column" (page 54).

Despite this, the book, as a whole, is of interest to paleontologists working in the field of paleoentomology and with groups of fossils occurring along with insects, as well as to geologists, particularly stratigraphers, who work in areas where fossil insects occur. The value of this book lies in its summing up of the results of paleoentomological research in the U.S.S.R., although the somewhat slanted emphasis on the Paleontological Institute work gives a lopsided idea of the present status of paleontomology in this country. As a resumé of factual data, the book under review unquestionably is a valuable reference for paleontologists and geologists working in various fields.

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## COMMENTS ON V.P. PETROV'S CRITICISM OF MY BOOK "PETROGRAPHY OF MAGMATIC ROCKS"[4]

by

B. Geytman

Izvestiya of the Academy of Sciences, U.S.S.R., Geologic Series, no. 9, 1958, carries an article by V.P. Petrov on my books on the petrography of igneous rocks, published in 1956 and 1957 by the Czechoslovakian Academy of Sciences. I am very grateful to V.P. Petrov for his analysis and criticism of my work, and I shall try to reply to it, to clarify my views, and thereby shed more light on some points of criticism.

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[4] Zamechaniya na kritiku V.P. Petrovym moyey knigi "Petrografiya magmaticheskikh gornykh porod."

1. With reference to shortcomings in the classification of igneous rocks, V.P. Petrov states on page 97 that I do not discriminate between the Cenozoic and Paleozoic types of extrusives. There is an unfortunate typographical error in the composition of the Table of extrusive rocks in my book. In the Table manuscript, all supersaturated and saturated rocks had paleovolcanic rocks in the upper line, and neovolcanic rocks in the lower. This is also mentioned in the first book (page 53): "Supersaturated and saturated extrusives are differentiated into paleovolcanic (with their names given in the upper line) and neovolcanic rocks, i.e., pre-Tertiary rocks are separated from Tertiary and younger rocks. The same is true for some undersaturated rocks, analogues of olivine gabbro." It is true, however, that this differentiation of rocks should have been illustrated more graphically in a Table, so that the reader could become acquainted with it, without recourse to the text. In this regard, in the second part of the books, the extrusives are described in just this way, as is pointed out by V.P. Petrov. A question arises — is it expedient to use different nomenclature for paleovolcanic and neovolcanic rocks? I believe it is not. A rock of a definite composition, such as andesite, remains as such irrespective of its age.

In many instances, map symbols may be used to indicate the age of andesite — Cambrian, Permian, or merely Paleozoic. As to other rocks, such as aplites and pegmatites, they are not included in my table because they belong not only to granites but to other groups as well.

2. With regard to the term "rhyolite," which V.P. Petrov regards as an "unappropriate English term," and recommends its substitution by "liparite," I gave the preference to "rhyolite" because of its priority and better correspondence to other terms (such as rhyodacite). The name "rhyolite" was suggested by F. Richthoven in 1860, and "liparite" by I. Rhota in 1861 (see 5, p. 265). It is used in those countries where the students were guided by the H. Rosenbusch works; it is now being gradually replaced by the term "rhyolite" (see also 1, p. 299).

3. With regard to monzonite, I want to emphasize that I discuss it in the second part of my work (p. 135), and I regard this rock as transitional from normal (nonalkaline) syenites to syenite-diorites (or gabbro-syenites) because the K-feldspar content in these rocks is approximately equal to its amount in plagioclase. Consequently, the only place to put monzonite in my Table was between syenite and syenite-diorite, because in it syenite and gabbro-syenite do not directly follow each other (see also Table in V.P. Petrov's article, [2]).

4. Concerning "vein rocks," I should like to state that I used this term because it is in veins that these rocks have their most typical development. Such rocks can be formed, for instance, along the periphery of larger intrusive bodies or else in their apophyses, as is stated in my book, in many instances, especially in the description of granite porphyries (Part One, pp. 32 and 39). I also state in Part One (p. 51) that, in my opinion, extrusive rocks should be differentiated in the same way as it is done by L.V. Pirsson and A. Knopf ([6], p. 162), i.e., by their textural features: 1) phanerites (granites, diorites, gabbros, with average grain size more than 1 mm); 2) microphanerites and porphyritic microphanerites (granite porphyries, diorite porphyrites); 3) aphanites and porphyry aphanites (rhyolites, andesites, basalt). If we adopt this basic differentiation, it would eliminate the difficulties with both the granite porphyries which form peripheral facies of some granite bodies and with typical granites which, in contrast, commonly form veins. However, the abandonment of the basic differentiation of extrusive rocks into deep-seated, vein, and extrusive, undoubtedly would arouse a widespread protest in Czechoslovakia because such an innovation, in addition to being rather odd, would contradict established views and usage.

I recall the great controversy brought about by substituting the term "quartz diorite" for "siliceous diorite" which I made in accordance with the international nomenclature.

5. In my book, the chapter on minerals of the extrusive rocks has a purpose different from that in manuals for optical determination of minerals; therein lies the reason for omitting the optical constants. This is stated in Part One (p. 69) where minerals are described from a chemical and a genetic point of view, in so far as the relationship between the composition of individual minerals and that of the enclosing rocks, etc. is concerned. I regarded as superfluous the inclusion of optical data also because they are given in my other book, "Rock-forming Minerals" (in collaboration with I. Konta, 1953). That book will appear in a second edition, in 1959.

6. Before replying to V.P. Petrov's reference to my "strictly formalistic approach to the differentiation of rocks into groups," (see [2], p. 99) I wish to explain just how I worked out the plan of Part Two of my book. First I proposed to consider in the groups of supersaturated, saturated, and undersaturated rocks, all deep seated, then all vein, and finally the corresponding extrusive rocks, as has been done by H. Rosenbusch ("Elements der Gesteinslehre" and "Mikroskopische

Physiographie der massigen Gesteine"). After lengthy deliberation, I selected a method which justified itself in my lectures at the Charles' University and had been used by that classic petrographer, F. Zirkel (1893-1894). This method considers rocks in a framework of a mineralogical classification, in groups of a definite mineralogical composition, disregarding the difference between intrusive and extrusive rocks. As a consequence, for instance, in the granite group the rocks are considered in the following order: granites, granite porphyries, granite aplites and pegmatites, finally quartz porphyries and rhyolites with corresponding volcanic glasses. This method facilitates the memorizing of the extrusive rock classification. We only need to know that the granite group is characterized by a preponderance of K-feldspar over a plagioclase more acid than No. 50, and this remains true not only for granites but for the other rocks. Under the other approach, by considering first all of the deep seated, then vein, and finally the extrusive rocks, their mineralogical composition would have to be learned in the same order, individually. Such a classification is hard on students; even the specialists make mistakes in memorizing. A similar method of study for extrusive rocks was selected by A.N. Zavaritskiy, in 1955, i.e., one year after I had finished my book and sent it to press.[5]

In conclusion, I should like to emphasize that my classification of rocks, worked out from the classifications by H. Rosenbusch and F. Zirkel, W.E. Treger, S.I. Schend, A. Johannsen, and P. Niggli, is built on a mineralogical basis. This classification also may be called quantitative because it determines a definite boundary between groups of granite and granodiorite, syenite and syenite-diorite; however, it does not circumscribe the extent of individual rocks, because none of the quantitative mineralogical classifications of extrusive rocks has achieved universal recognition, as yet. In the meantime, when I wish to differentiate syenite from granite, for instance, I am satisfied to know that quartz is present in syenite, in contrast to granite, only as a secondary mineral.

My classification demonstrates that its author is not an advocate of the so-called genetic classifications. Such classifications, on the whole, cannot be sufficiently precise, in both petrography and geology, because the views on the origin of many rocks change with the development of our knowledge. I am convinced that — as pointed out by I. Rot as early as the last century — that a unity of mineralogical and chemical classifications will never be attained; I regard therefore any chemical classification as a supplement to the mineralogical classification. Following this line of thought, I cite only the chemical analyses for individual groups of extrusive rocks, without recomputing them according to the method of some chemical classifications; and I use a ternary diagram with five mutually related components for a graphic illustration of the chemism of rocks.

With regard to V.P. Petrov's reference to descriptions of earlier mentioned areas in Part Two of my book, I have this to say. In Part Two, I do not cite material by individual areas as such, but refer to definite types of rocks, so that a student who will have found a similar rock anywhere, will be able to compare it with rocks from other localities. For that purpose he will find necessary data in my book, along with references to other publications. The rocks of Czechoslovakia, classified by provinces or by other regional units, should be described in a special book, such as "Petrography of the Czechoslovakian Republic," as V.P. Petrov recommends at the end of his article.

7. These remarks of mine deal with only a few of the topics touched upon by V.P. Petrov in his critical article. Therefore this should not be regarded as a debate with V.P. Petrov who, naturally, for lack of space, could not have brought forth all the details and given a comprehensive review of my ideas.

[5] A.N. Zavaritskiy, author of the "Extrusive Rocks," published in 1955, passed away in 1952. Russian Editor.

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## LETTER TO THE EDITORS OF IZVESTIYA OF THE ACADEMY OF SCIENCES, U.S.S.R., GEOLOGIC SERIES[6]

I request the publication in your magazine, of my brief remarks on the paper of S.A. Arkhipov and Yu.A. Lavrushin, "The Problem of Yenisey Drainage During the Maximum and the Zyryanian Glaciation" (Izv. Akademiya Nauk SSSR, Geologic Series, no. 6, 1957).

The question: "Where did the water go from rivers which flowed to the north, when glaciers covered the north of Western Siberia?" was posed as early as 1901-1902, by G.I. Tanfil'yev. He offered the hypothesis of a large lake with a southern outlet, because its northern end was dammed; he did not rule out the possibility of a northern outlet, around the eastern end of the glacier (G.I. Tanfil'yev, Geography of Russia...", part II, 2nd edition, 1903). When it became known that glaciers had been formed in the east as well as in the west of the plain, the outflow problem broadened, to wit, where did the waters of the three giant rivers, Irtysh, Ob, and Yenisey flow? Several views are known on this subject: these waters flowed north between the glaciers (Ya.S. Edelsteyn), over the glaciers (V.A. Obruchev), under them (V.N. Saks), around the glaciers which attained their maximum at different times (N.A. Naginskiy), etc.

"The original paleogeographical conception" of the two authors of the paper in question, is that the flow problem, as previously formulated, is explained away — for the Yenisey only, to be sure, and without any explanation as to why such exception may be taken for one of the three largest rivers of Western Siberia. According to the authors, the flow problem was nonexistent because the amount of water in the Yenisey was reduced several times during the glaciation; what water there was did spread along the old deep valley, with little of it reaching the glacier. Thus, not enough water accumulated during the entire glacial period, for it to flow over the Ob-Yenisey water divide. The authors believe that their concept can be supported, "qualitatively if not quantitatively," by the data on present hydrological conditions of the Yenisey basin. The total annual discharge of the main tributaries to the Yenisey (the two Tunguskas and the Angara) is more than that for the Yenisey and its other tributaries. "The abundance of water in the main tributaries and in the Yenisey itself depends on the thickness and especially on complete melting of the snow pack." The Angara alone has a definite discharge, 47% of which is accounted for by the Baykal waters. On the basis of these data, the authors propose the following in their computations: 1) take into account "only the upper reaches of the Yenisey basin, approximately as far as the Angara mouth, as existing at the maximum Samara glaciations (in that event, the average annual rate of flow for the river would be 3,346 $m^3$/sec); and 2) "to count out the snow and rain water for the Yenisey and its tributaries," as a result of which their discharge will be reduced ten times." Thence the conclusion that "the basin in front of the glacier could not, for that reason, develop to a large size" (page 93).

These considerations and computations are fully unsubstantiated. One cannot count out these factors: 1) the Angara which joins the Yenisey 900 kilometers south of the maximum glaciation boundary, and the Podkamennaya Tunguska which flows into the Yenisey 400 kilometers south of the Zyryanian glaciation boundary (Fig. 5, p. 99); and 2) snow and especially rains: the run-off period could have been shorter than the present, but more turbulent. However, even if we agree with all of the simplifications assumed by the authors and compute the lake volume in the lower Yenisey course for the thousands of years of glaciation, an elementary oversight of the authors will be especially glaring. Let us assume that the Yenisey discharge during the glaciation was merely 300 $m^3$/sec (as against the present 17,400 $m^3$/sec!); in that event, in less than 2,500 years a lake should have been formed with an area of 100,000 $km^2$ and 200 meters deep. Consequently, the Yenisey, held back by the glacier, would have created a vast flood in a comparatively short time, and its waters would have spilled over the Ob-Yenisey water divide.

The authors assert that this spill-over has not been confirmed by field data; however, there are many inaccuracies in their references, distorting the meaning of the references cited. L.N. Ivanovskiy (as referred to on page 94) believes as possible "a bend to the west in the ancient Yenisey valley," northwest of Krasnoyarsk (see L.N. Ivanovskiy's paper, page 268). Yu.P. Kazanskiy does not "deny any evidence of middle Tertiary deposits" in the Kas and Sym basins, as the authors say (page 94). He states, on the contrary, that "According to our data...sediments in the valley of the Sym River are middle Tertiary" (see Yu.P. Kazanskiy's paper, page 185). The authors cite the conclusions of S.B. Shatskiy and V.V. Mizerov, who worked in that area,

[6] Pis'mo v redaktsiyu zhurnala "izvestiya AN SSSR, seriya geologicheskaya."

to the effect that the Yenisey had a western outlet, during glaciation (page 92); however, for some reason they do not take it into account.

The authors believe that, "summing up all this, we can arrive at a quite definite conclusion that the idea of an outlet for the alleged excess of the Yenisey waters during the glacial period ...is a guess without much substantiation."

Our own conclusion is quite opposite. The "new paleogeographical concept" of the Yenisey discharge during the glaciation — which has neither the quantitative nor qualitative substantiation — should be rejected as erroneous.

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N. A. Naginskiy

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# CHRONICLE[1]

## PLENARY MEETING OF THE SECTION OF GEOLOGIC-GEOGRAPHIC SCIENCES, ACADEMY OF SCIENCES, U.S.S.R., MARCH 25, 1959[2]

The annual meeting of the Section of Geologic-Geographic Sciences (OGGN) was held on March 25, 1959, in the Conference Hall of the Academy of Sciences, U.S.S.R., Moscow.

Besides the academicians and corresponding members, scientific collaborators of the laboratories of the several institutes of the OGGN system, the Siberian section and the affiliates of the Academy of Sciences, U.S.S.R., and of the academies of the national republics, the participants included representatives of scientific research institutes of the Ministry of Geology and Conservation of Mineral Resources of the U.S.S.R., and specialists in the field of geology from the Moscow schools of higher learning.

Academician D.I. Shcherbakov, Secretary of the OGGN read his address, "The XXI Conference of the Communist Party of the Soviet Union (CPSU) and the Problems of Geologic-Geographic Sciences."

He pointed out that the XXI Conference of the CPSU drew a grandiose program of an all-out building up of the communist society in this country. This program is expressed in the theses of N.S. Khrushchev on the Seven-Year Plan of development in the people's economy in the U.S.S.R., which emphasize the decisive importance of the historic goal of the creation of a material base for communism in order to catch up with and overtake the most developed capitalist countries in per capita production.

In the light of this task, immense importance is attached to science; first to Physics, then to Chemistry, Geology, and others. These sciences must be developed along the lines of the most rapid and effective return for the state economy, because the time factor is of great importance in the rivalry of the two systems — the capitalistic and the socialistic.

In the time interval between the XX and XXI conferences of the CPSU, the OGGN organization and its laboratory base have been strengthened, its research staff has grown, and scientific effort began to be concentrated in the fields of the most important current problems. However, there is a scattering of effort not compatible with modern demands among the organizations of this Section.

The main purpose of geologic study within the framework of the Seven-Year Plan, is the search and exploration for mineral resources which, in turn, are the foundation of the planned growth of state economy. The patterns must be determined in the distribution of the most important minerals throughout the earth's crust (such as oil, natural gas, coal, ferrous and nonferrous metals, rare and radioactive elements) as the criteria of their presence in the U.S.S.R. The knowledge of spatial distribution of minerals is a prerequisite for the comprehensive and successful search for them.

It is expedient to differentiate the research in this field as follows: 1) minerals of a sedimentary origin; 2) minerals of an igneous origin; 3) oil and combustible gases; 4) coal and carbonaceous shales; 5) rare and disperse elements; 6) the formation and distribution of ground waters.

The scientific organizations of this Section must continue their theoretical work, along with the work on problems in individual branches of geology that are closely related to the main course of geologic study, such as 1) scientific principles and methods of study in metallogeny of ore regions; 2) a general theory of ore formation, including the hidden (blind) mineralization; 3) igneous complexes

[1] Khronika.

[2] Obshcheye sobraniye otdeleniya geologo-geograficheskikh nauk AN SSSR 25 Marta 1959 g.

nd the physical and chemical patterns in etrology; 4) genetic types of rare-element eposits and their geochemical features; ) classification of tectonic forms, regional ectonics, a world tectonic map; 6) a single tratigraphic scale for the U.S.S.R.; 7) a geo-hronologic scale of the U.S.S.R., expressed n absolute age.

The second task of geological organizations s a joint solution of interdepartmental prob-ems and a coordination of research in basic elds. A specific instance is a unified plan f geochemical research for the several stitutes; in the field of geology of ore eposits, their petrography, mineralogy, and eochemistry; mineralogy, geochemistry, and rystallography of rare elements; geochem-stry and analytic chemistry; as well as plans or joint interdepartmental theoretical research n the field of 1) depth structure of the arth's crust (in cooperation with the Institute f the Earth's Physics); 2) geochemical rocesses at higher temperatures and pres-ures (in cooperation with the Institute of eochemistry and Analytic Chemistry).

The third task is to strengthen the contact etween science and life, through personal ontacts and cooperation with specialists from ndustrial organizations and other institutions uch as the Gosplan (State Planning) U.S.S.R., Iinistry of Geology and Conservation, Glav-eologiya (Main Geologic Administration) SFSR (Russian Soviet Federated Socialist epublic). Very useful for such contact might e information on projects underway, given ut at meetings and conferences and in special ulletins.

All these problems suggest the necessity of well-conceived organization of scientific ork. Complex problems should be attacked y a staff of specialists competent in their espective fields, and supported by necessary aboratory facilities.

To direct the work along the main line and coordinate the research, a single advisory oard should be created, in cooperation with ne Ministry of Geology and Conservation and ith the participation of representatives from ther departments and organizations.

In dealing with geographic problems, cademician D.I. Shcherbakov noted that geo-raphic study, carried on by the several nstitutes of the OGGN, is, on the whole, at ne level of modern science and adequate to ne demands on it. He named the three main asks: 1) the elimination of blank spots on ne geographic map of the world; 2) the study f elemental natural phenomena and processes; ) generalization of material extant on natural esources and on the economy of the several egions of the U.S.S.R., the people's democracies, and the capitalist countries — all of them, on the whole, conforming to the goals set up for Soviet science in the resolutions of the XXI Conference of the CPSU. They are formulated as an overall geographic problem designated within the scientific plan of the Academy of Sciences, U.S.S.R. as "Complex Geographic, Cryological, and Oceanographic Study of Natural Conditions and Resources of the U.S.S.R. and the Means of Their Utilization."

The report has stressed the substantial growth in the organization of the OGGN, for the last year, because of the ever-growing international contacts, the participation in international conferences, the working-out of the most important fields of scientific effort, the participation in the work of Gosplan in the formulation of the Seven-Year Plan for the development of the economy of the U.S.S.R., the assistance to the national republican academies and affiliates of the Academy of Sciences, U.S.S.R., etc. In addition, Academician D.I. Shcherbakov noted that the Section Bureau did not put sufficient emphasis on the more important major scientific problems and on the direction of newly organized committees and councils. The organization of reports by the academicians and corresponding members also has not been carried out.

The speaker concluded by expressing his conviction that all members of the OGGN system will make their full contribution in effort and initiative, toward the fulfillment of goals set up by the XXI Conference of the CPSU.

The report by Academician D.I. Shcherbakov was followed by a comprehensive exchange of opinions. Participating in the discussion were Corresponding Member V.V. Belousov, Academician A.L. Yanshin, Academician N.M. Strakhov, Academician D.V. Nalivkin, Academician N.S. Shatskiy, Corresponding Member I.P. Gerasimov, Academician N.V. Belov, Academician A.A. Trofimchuk, A.D. Yershov (All-Union Institute of Mineral Raw Material), A.A. Beus (Institute of Mineralogy, Geochemistry, and Crystallochemistry of Rare Minerals, Akademiya Nauk, U.S.S.R.) and Academician K.I. Satpayev.

In the opinion of V.V. Belousov, geology in the Academy of Sciences system, does not occupy the position commensurate with its part in the economy of the country. This is explained not only by the leading position of physics and chemistry in the present state of the development of science, but also by the lack of major scientific generalizations and of comprehensive research (in geology).

Conceding the importance of the tetconic map compiled by the Academy, as a major

general work, V.V. Belousov believes that its method of compilation, worked out as early as in the thirties by A.D. Arkhangel'skiy, is not quite compatible with present requirements and should be amended by the application of diversified methods in the compilation of tectonic maps.

The only new method of geologic study, recommended by the Geologic Institute, is the study of sedimentary formations, to be used in predicting the distribution of useful minerals. However, the work on sedimentary formations does not clarify the problems of distribution and origin of minerals. In conclusion, V.V. Belousov pointed out the need for methods of solving the problems outlined in the field of geology, in addition to their delineation.

Academician A.L. Yanshin believes that the tectonic map, compiled under the direction of N.S. Shatskiy, could not have been made in the thirties, because geologists then did not have such extensive and reliable material, as they now have. The tectonic map, as a generalization of geologic facts, reflects a fairly high development of geology in the U.S.S.R.; this has been shown by the international recognition of this map at the Mexican Session of the International Geological Congress and by the award of a prize for it at the International Exposition in Brussels, 1958; also by the fact that tectonic maps, made on the same basis with but a few changes, are being used by nearly all geological organizations as a criterion for forecasting in metallogenic study.

According to Academician A.L. Yanshin, another undertaking, more valuable than any of those initiated in the thirties, is the development of the formation approach. To be sure, there is much controversy in the evaluation of this method, and the formation study has not been advanced far enough; but this is only natural for the beginning of a new development in science.

A new field of prime importance is the study of patterns in the distribution of minerals, this despite the low status of such knowledge at the present time. This problem was formulated in the fifties; it could not have originated before because of the lack of field data.

A.L. Yanshin agrees that geology is no longer holding its former place among the disciplines. He explains this by the following reasons:

1. At the present stage of scientific development, priority is given to physics and chemistry, and perhaps to biophysics and biochemistry.

2. There are no good contacts between workers in theoretical and workers in practical geology; as a result, the role of geology in the study and assimilation of mineral raw materials is underestimated. Such was the case in the problem of Siberian diamonds, although it is well known that many scientific investigations, beginning with the work of Academician V.S. Sobolev, were associated with the discovery and study of the trap-rock zone on the Siberian platform, with the establishment of identity of Siberian and South African trap rocks, and with the discovery of patterns in the distribution of the trap rocks. Little noticed, also, was scientific work in the discovery of the Kustanay magnetite deposit. Such instances are numerous, and such disregard for scientific discoveries and forecasts lowers public opinion as to the value of geology.

3. Some Soviet and foreign geologists (such as V.V. Belousov and G. Bernal) believe that old classic geology has outlived its usefulness, and that further development of geology requires physical and chemical methods of study — number and measure. Such a view belittles the great theoretical and practical importance of geology with its own proven adequate methods, which have been of great help to our science and to the economy of our country.

We geologists must not acquiesce to an underestimation of the part of science in geologic practice, nor of the value of geologic methods, properly speaking, in the study of the earth's interior.

Academician N.M. Strakhov recognizes the importance of the study method in the problem of the regular distribution of minerals. He believes with V.V. Belousov that there is much confusion in the definition of the sedimentary formations method as formulated by N.S. Shatskiy and N.P. Kheraskov. He believes it is methodologically wrong to recognize the empiric school of the study of sedimentary formation as the only correct one. He would apply diversified methods to this leading problem, including facies-genetic analysis.

Academician D.V. Nalivkin explains the deterioration of geology's position among other sciences by the fact that geologists presented only small-scale specific results in their works; he believes the tectonic map to be the only outstanding achievement of great theoretical and practical value.

In the principal field of geology, which is the determination of patterns in the origin and distribution of minerals, he recommends a concentration of effort on the following three problems: 1) metallogenic study; 2) a study of

he oil and gas potential of the country; 3) oal deposits of the U.S.S.R.

In this task, it is important to use diver-ified methods. In this D.V. Nalivkin is in greement with N.M. Strakhov.

Academician N.S. Shatskiy opened his talk n the subject of the position of geology in ne Academy of Sciences, U.S.S.R. He tated that the level of our knowledge does ot rise evenly and gradually, but that each cience grows by leaps and bounds. Each ew shift in the history of a science is pre-eded by a preparation stage, a period of ulling new facts for interesting generaliza-ions, and by important practical conclusions. 'oday's geology, according to N.S. Shatskiy, s at one of these stages. It is an unruly cience, with new ideas and methods being ntensively developed; if it has stepped down o a secondary position, one of the reasons or it is the propaganda that geology as such, as outlived itself, that new achievements in t can be made only through novel data btained by new and precise methods of study, vith number and measure introduced into eology.

Of course, the precision of data is an mportant condition of success, and it should e striven for. It is not true, however, that his precision is the gist of geology as a cience. Equally not true is the assertion of . Bernal that there has not been any quali-ative advance in geology since Darwin.

At the turn of this century, when an mportant break-through was made in natural cience (about the year 1911 for geology), eology became the science of the develop-nent of the earth's crust, rather than the cience of the history of the earth's surface. Consequently, the value of geology is not only n its being a means of procuring those natu-al resources which are the material basis f development of a country, but in being the nly natural science using the historical nethod of study, thanks to its method of hronology (stratigraphy). This methodologic spect of geology, and its generally recog-ized position as a science, should be empha-ized in the future.

Although recognizing the leading part of hysics and chemistry, we should not think hat everything in geology depends on them. The experience of the Commission on the Determination of Absolute Age of Geologic Formations shows that precision methods are nvalid without a purely geologic analysis.

With regard to the method of work in the nain field — patterns in the distribution of ninerals — N.S. Shatskiy believes a study of efinite sedimentary complexes (the formation method) to be the correct one. Any rock sequence, such as the Donbas coal measures, however diversified in the nature and the age of its component rocks, is a discrete natural body; such a conclusion can be arrived at not by theoretical considerations on a sedimentary process but experimentally, i.e., empirically, and it should not be replaced.

The formation method — as applied, for instance, to manganese ores — has not as yet received its proper recognition in this country, although it is beginning to be applied abroad: in Germany; in France in determining the origin of manganese in the Pyrenees; in the U.S.A., too, our classifi-cation has been accepted as the best of the empirical methods.

The study method must be diversified. The comparative-historical method in lithology should also be developed. N.M. Strakhov has been provided every facility for this purpose in the Geological Institute.

In conclusion, N.M. Shatskiy commented on the complexity of making tectonic maps (theoretical rather than technical), in changing from small- to large-scale maps. The suc-cess in the compilation of tectonic maps of Europe and Eurasia, and the joint work with the Geological Institute of the Chinese Acad-emy of Sciences, are only the beginning in the application of tectonic maps to geologic practice. When such maps are made accord-ing to firmly established rules, the Academy of Sciences will then consider its task accom-plished.

Academician I.P. Gerasimov spoke on work of the Geography Institute, Akademiya Nauk, U.S.S.R. Its prime task is a scientific generalization of geographic material from this country and abroad; the next task is the elucidation of general and specific the .es in geography. These problems are viewed in the light of the main problem, "Natural Resources and Productive Forces of Our Country."

Many of our institutions are engaged in geographic study at the Academy and in other places. Under such conditions, an efficient organization and coordination of work is very important. However, even within the Academy system, neither the Council for the Study of Productive Forces nor the Section of Biological Sciences have supported the Institute position on this subject.

The suggested reorganization of scientific work would promote consolidation of scientific effort in carrying out the resolution of the XXI Conference of the CPSU.

Academician N.V. Belov believes that

mineralogy is even of greater historical significance than geology in the field of nature study, because minerals are objects of geologic processes; accordingly, the knowledge of their structure produces important results. Despite this, little attention is paid to mineralogy in domestic science, although study in this field may promote our knowledge of thermodynamic processes. More intensive effort is urged in the study of mineralogy, especially in the field of crystallochemistry which should take its proper place among the geologic sciences, as it does abroad, specifically in Bulgaria.

Academician A.A. Trofimchuk noted the importance of oil and gas among the resources of the country, in the light of the resolution of the XXI Conference of the CPSU, and he reported on the progress of work in the Siberian Section of Akademiya Nauk, U.S.S.R.

In his opinion, the views which consider geology as a second-class science are the result of the confined working conditions of the Moscow and Leningrad scientists. In contrast, the organization of the Siberian Section started with a Geological Institute, because industrial organizations such as Sovnarkhozes had set up as a task for the geologists, the establishment of scientific concepts applicable to the search for mineral resources.

What most Siberian geologists need is guidance from our leading specialists in the proper direction of applied study.

A.D. Yershov (All-Union Institute of Mineral Raw Materials) noted the need for an effective method of large-scale forecasting and for a fuller study of properties of rocks and minerals, along the lines set forth by N.V. Belov.

This is a large and momentous task, to be carried out in accordance with practical demands under the direction of the Academy of Sciences, through joint efforts of geologists and of other nonacademic organizations.

A.A. Beus (Institute of Mineralogy, Geochemistry, and Crystallography of Rare Elements, Akademiya Nauk, U.S.S.R.) spoke on the importance of geochemistry, chiefly in revealing the migration and concentration of elements, which is the deciding factor in the formation of ore deposits. Without considering the geochemical aspect of a mineralization process, important theoretical problems in geology can not be solved.

In the opinion of Academician K.I. Satpayev, geology has a deservedly high place in the Seven-Year Plan. A united effort of scientists and field workers is needed to fulfill this task, assisted by a broadened laboratory work base enabling geologists ot utilize most diversified methods of investigation.

In his concluding address, Academician D.I. Shcherbakov voiced his conviction that the problems posed to the geologists will be solved. An active participation of the members of the Section in the discussion of the task to be done is a pledge of our success.

After the discussion of the report of the Academic Secretary, Corresponding Member L.A. Zenkevich spoke on some results of the study of the World Ocean.

The current organizational problems were also brought up for discussion. The Section Bureau was increased by the following additional members: Corresponding Members M.F. Mirchik, V.I. Smirnov, and P.A. Shumskiy.

The following Directors were elected: N.S. Shatskiy, of the Geological Institute; F.V. Chukhrov, of the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry; K.A. Vlasov, of the Institute of Mineralogy, Geochemistry, and Crystallochemistry of Rare Elements; M.F. Mirchink, of the Institute of Geology and Exploitation of Minerals; I.P. Gerasimov, of the Institute of Geography; P.A. Shumskiy, of the V.A. Obruchev Permafrost Institute; V.G. Kort, of the Oceanology Institute; A.A. Polkanov, of the Laboratory of Precambrian Geology; N.G. Kell', of the Aeromethod Laboratory; V.I. Vlodavets, of the Volcanology Laboratory; S.V. Kalesnik, of the Limnology Laboratory; G.P. Barsanov, of the A.Ye. Fersman Mineralogical Museum; and S.S. Kuznetsov, of the A.P. Karpinskiy Geological Museum.

In conclusion, Academician D.V. Nalivkin spoke to the meeting on the preparations for the XXI International Geographic Congress.

## ACADEMICIAN A.N. ZAVARITSKIY, MEMORIAL

A joint meeting of scientists, members of councils of the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Academy of Sciences, U.S.S.R., and the Volcanology Laboratory, Academy of Sciences, U.S.S.R., was held on March 18, 1959 in commemoration of the 75th birthday anniversary of Academician Aleksandr Nikolayevich Zavaritskiy, who passed away on June 23, 1952.

Noted workers in the field of geology, numerous pupils, friends, and relatives of Aleksandr Nikolayevich gathered to honor the

emory of this outstanding geologist and etrographer.

The meeting was opened by Academician .I. Shcherbakov, Academic Secretary of e Section of Geologic-Geographic Sciences, .S.S.R., who noted the considerable contri- ution of A.N. Zavaritskiy, as a scientist, the solution of problems in petrology, etrochemistry, and other branches of eology related to the study of the earth's rust.

Academician A.G. Betekhtin reminisced, with lantern slides, on his collaboration with A.N. Zavaritskiy, from 1923 till the latter's death.

The development of the petrologic ideas of A.N. Zavaritskiy was related by his pupils: Academician V.S. Sobolev read his paper on "Some phase relationships in the system nepheline-kaliophyllite-anorthite-silica;" then Academician D.S. Korzhinskiy spoke on "Acid-alkaline interaction of magma components."